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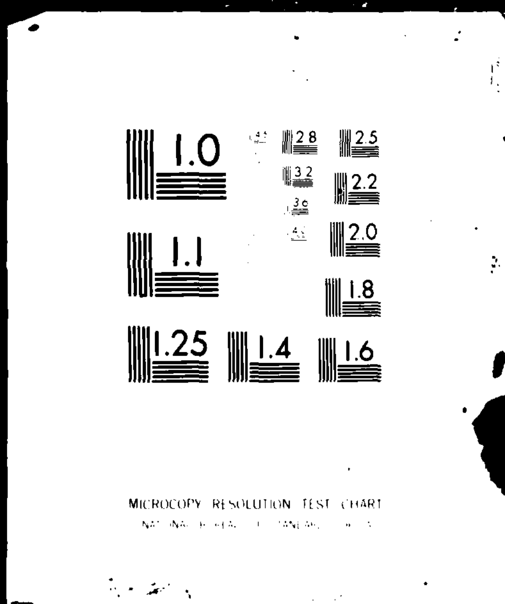

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EVALUATION OF DCS III TRANSMISSION ALTERNATIVES PHASE II TASK 2 FINAL REPORT

16 NOVEMBER 1981

Prepared for
Defense Communications Agency
Defense Communications Engineering Center
Reston, Virginia 22090

Contract No. DCA 100–79–C–0044

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This report is the final of a series that document the study, analysis, and evaluation of the use of advanced communications technology in the Defense Communications System. The purpose of the overall study was to project the capability of potential transmission media into the future, and to assess their comparative utility for DCS application in the years 2000 and beyond. The final phase of the study contained in this report addresses the use of millimeter wave LOS radio and fiber optic transmission in central Germany and

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Hawaii. The system performance was modeled using the parameter of "Average Network Availability". Network cost and performance was evaluated for a number of different configurations, and under a variety of stress conditions.

EVALUATION OF DCS III TRANSMISSION ALTERNATIVES PHASE II TASK 2 FINAL REPORT

16 NOVEMBER 1981

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FOREWORD AND ACKNOWLEDGEMENT

This Phase II Task 2 Final Report is the second of the reports of the Phase II effort of Evaluation of DCS III Transmission Alternatives Study. Reports of the Phase I and Phase II Task 1 effort consist of six volumes. These volumes are:

1. Phase IA Final Report, Evaluation of DCS III Transmission Alternatives, AD 101359
2. Appendix A, Transmission Media, AD 101360
3. Appendix B, Regulatory Barriers, AD 101361
4. Appendix C, Regional Consideration and Characterization, AD 101362
5. Phase IB Final Report, Evaluation of DCS III Transmission Alternatives, AD 101363.
6. Phase II Task 1 Final Report, Evaluation of DCS III Transmission Alternatives.

Project work, as documented in the above noted reports and appendices, has been performed by the Defense and Space Systems Group, TRW Inc., and by TRW's subcontractor, Page Communications Engineers, Inc., Northrop Corporation, for the Defense Communications Engineering Center, Defense Communications Agency, under Contract No. DCA 100-79-C-0044.

This project has been managed by Dr. T. M. Chu of the DSSG of TRW Inc., and subcontracted work by Mr. R. A. Pickens of Page Communications. TRW contributors of work presented in this report are Messrs. S. H. Lin, D. L. Segel, and Drs. T. M. Chu and C. Y. Yoon. The computer code CMANA for network performance evaluation has been developed by Dr. C. H. Pian under the TRW fund. Page's contributors are Messrs. T. Loeffler, P. Hill, and W. Nehl.

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1.0 INTRODUCTION

This report documents the results of the Task 2 of the Phase II effort of the "Evaluation of DCS III Transmission Alternatives" study. This study was conducted for the Defense Communications Engineering Center (DCEC), Defense Communications Agency (DCA) in accordance with Contract No. DCA100-79-C-0044. It was performed by the Defense and Space System Group, TRW, Inc. and by TRW's subcontractor, Page Communications Engineers, Inc., Northrop Corporation.

Since the results presented in this report are the second part of the second year effort of a two year contract, it is deemed helpful to recognize, in advance, the objectives and scope of the DCS III Study program. With this background information, the results presented here can then be placed in the proper perspective for those readers who have not read the Phase I reports (Ref. 1-1 and 1-2) and Phase II Task 1 Report (Ref. 1-3). Therefore, the purpose, scope and objective of the entire DCS III Study program are discussed in this section. A brief summary of Phase I results and findings are given in the following Section 2. Some necessary background material extracted from Phase II Task 1 Report is presented in Section 3 for ready reference.

1.1 OVERALL PURPOSE OF THE DCS III STUDY PROGRAM

The Defense Communications System (DCS), since its establishment in 1960 has been in a continuous process of growth and evolution. This process is a direct response to the changes of requirements and the advancement of communications technology. The DCS is currently in the transition period from an analog system to a first generation digital system. According to various project plans and schedules, components of the digital DCS will be implemented during the period of FY 80 to FY 85 and will be fully operational by FY 85. Particular attention has been given to digital transmission facilities, switching capability, particulary for interactive data transfer and computer data interchange traffic, and technical control facilities.

As a general rule, the life span of communications systems and electronics is about fifteen years. Therefore, by the year 2000, the DCS now being implemented needs to be gradually replaced by either new and exactly the same equipment or by systems and equipments utilizing new

transmission media and/or communications technologies which are either currently being developed or would be developed from now to the year 2000. This will result in a future DCS, termed DCS III in this report.

It usually takes five to ten years to develop a new system, from the time of formulating a system concept to the time of implementing the developed system. A longer period of time is required when new and unproven technology is utilized. Therefore now is the time to examine alternatives for implementing the future DCS transmission subsystem.

To provide a basis for the evolving architecture design of the third generation DCS for the years beyond 2000, it is necessary to identify alternative transmission media, communication technologies, system engineering concepts and designs. In addition, international, regional, and national regulatory barriers which may impact alternative media selection and transmission system designs need to be identified and documented. To be able to judge the practical utility of each transmission medium, networks using the various media are designed to fulfill specified requirements. Performance and life cycle cost of various networks employing different transmission medium are then evaluated and estimated. By comparing each network's performance and cost, the effectiveness of various promising media can be assessed.

In summary, the primary purpose of the DCS III Study Program is to project the capability of potential transmission media and to assess their comparative utility for DCS in the years beyond 2000.

1.2 SCOPE AND OBJECTIVE OF THE DCS III STUDY TASKS

The DCS III study is composed of two phases and seven tasks with specified objectives for each task. These tasks are:

1. Phase I:

   a. Phase IA:

      Task 1. DCS III Transmission Media Alternatives

      Task 2. Development of Evolving DCS Transmission System Alternatives

      Task 3. Identification of Technology and Regulatory Barriers.

b. Phase IB:

Task 1. Comparative Evaluation of Alternatives

Task 2. Relative Cost.

2. Phase II:

Task 1. Overlay of Special User Transmission Requirements

Task 2. Re-evaluation of Alternatives.

Phase IA and Phase IB constituted the first year effort of the DCS III study program and phase II constitutes the second year effort.

The objective of Task 1 of Phase IA was to identify promising transmission media for the DCS III time frame, to assess or forecast capability, to examine limitations and restraints, and to recommend needed research and development effort to resolve uncertainties in applications. The objective of Task 2 of Phase IA was to develop two candidate transmission systems employing appropriate transmission media for certain specified areas, satisfying the required capacities and connectivities of each area. Three areas of interest are specified for this purpose. These areas are Oahu Island of the Hawaiian Islands, the central portion of the Federal Republic of Germany, and Turkey. The objective of Task 3 of Phase IA is self-explanatory. Related international, regional and national regulations, rules, procedures, standards, and recommendations which have impact on transmission system design are collected, organized, and reviewed.

The objectives of Phase IB were to comparatively evaluate the performance and cost of those alternative transmission systems developed in Task 2 of Phase I. In Task 1, of Phase IB, system performance measures were defined and evaluation methodology developed for each medium. Then system performance of each candidate alternative design was evaluated and compared. In Task 2, the life cycle cost of each of the candidate transmission systems was estimated. Those costs include the cost of development, acquisition, operation, maintenance, and support of the system.

The objective of the Phase II effort, in accordance with the Statement of Work is twofold. The first task is to overlay wideband user's requirements on the common user alternative transmission systems designed in Task 2 of Phase IA for the three specified areas. The second task is to evaluate performance of those alternative systems supporting both common user and wideband user needs, and to estimate life-cycle cost of those systems for both common and wideband users.

However, based on the results and findings of the Phase I effort, the scope and objective of the Phase II effort has been modified. There are two major changes. The first is that the number of areas of study have been reduced from three to two; Turkey will not be considered in Phase II. The second is that four and five specified alternatives are required to be designed, for Hawaii and Germany, respectively, not the Phase IB two preliminary designs for each area.

1.3 PREVIOUS DCS III STUDY REPORTS

This report documents results and findings of the last task of this DCS III Study program. Other reports issued previously under this program are the following (Ref. 1-1, 1-2 and 1-3):

1. Phase IA Final Report, Evaluation of DCS III Transmission Alternatives, AD 101359
2. Appendix A, Transmission Media, AD 101360
3. Appendix B, Regulatory Barriers, AD 101361
4. Appendix C, Regional Consideration and Characterizations, AD 101362
5. Phase IB Final Report, Evaluation of DCS III Transmission Alternatives, AD 101363.
6. Phase II Task 1 Final Report, Evaluation of DCS III Transmission Alternatives.

These volumes and the present one present the total accumulated effort of the program.

1.4 ORGANIZATION OF PHASE II TASK 2 REPORT

This report is organized into seven sections of which this is Section 1, Introduction.

Section 2, entitled Summary of DCS III Previous Study Effort, describes the finding and results of Phase I effort and emphasizes those materials which impact Phase II. In this section, some Phase II Task 1 results which are closely related to the work presented in this report are briefly summarized. In Section 3, proposed transmission alternatives for Hawaii and Central Germany are re-evaluated for their performance in the benign environment. The measure of network performance in a stressed condition, Average Network Availability (ANA) is defined and discussed in Section 4, and the developed computer model is also described. An example network has been adopted to demonstrate the meaning, and approach and methodology of ANA analysis. ANA analysis results of all proposed alternatives are presented in this section. Section 5 provides cost models for the three transmission media, microwave LOS, millimeter wave LOS, and fiber optics. These models are used as a basis to estimate proposed transmission alternatives ten year life cycle costs which are presented in Section 6. Summary, conclusions, and recommendations are provided in Section 7.

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2.0 SUMMARY OF DCS III PREVIOUS STUDY EFFORT

The results of the Phase IA and Phase IB effort are briefly summarized in Sections 2.1 and 2.2 respectively. The impacts of these results upon the Phase II work are presented in Section 2.3. Some topics of Phase II Task 1 Report (Ref. 1-3) closely related to the work presented in this report are summarized in Section 2.4. However, this report is not intended to be a stand alone document, and reference to Phase II Task 1 Final Report is needed for some detailed information and topics not covered in Section 2-4.

2.1 SUMMARY OF PHASE IA REPORT

Task 1 identified four broad categories of promising transmission media deemed worthy of study. These categories are guided wave utilizing a conductor, radio wave utilizing radiated energy, airborne relay platforms and other alternatives to electromagnetic communication waves. The media considered in each group are listed in Table 2-1. All media were subjected to extensive study. The performance parameters of each media are summarized in the Phase IA Final Report and further developed in Appendix A of that report (Ref. 1-1).

It was concluded that in light of the three geographical areas of implementation, attention was focused on coaxial cable, optical fibers, millimeter waves, EHF satellite, aircraft and tethered ballons as the most promising media worthy of further detailed study.

These six media were applied in Task 2 to the development of two candidate transmission systems for each area of interest as shown in Table 2-2. Initial action consisted of gathering information on the existing and planned DCS trunks in each of the three areas. This information was for the most part derived from DCA drawings and trunking documents. Major topics addressed were:

- Network trunking requirements analysis
- Topographic and climatic considerations
- Regional characteristics considerations
- Frequency band availability
- Medium or media selections
- Network design methodology.

The reports do not reflect consideration of multiplexer, and switching schemes because these elements were specifically excluded from consideration in this study. It is assumed that the DRAMA multiplexer equipment will be used for DCS III.

Table 2-1. Alternative Transmission Media Investigated

I.	Guided Waves
	1. Coaxial Cable
	2. Millimeter Waveguide
	3. Beam Waveguide
	4. Optical Fibers
	5. Submarine Cables
II.	Radio Waves
	1. Terrestrial Microwave Line-of-Sight Transmission
	2. Tropospheric Scatter Communication
	3. Millimeter Waves
	4. EHF Satellite
	5. Packet Radio
	6. Meteor-Burst Communications System
	7. Radio Frequency Spectrum
III.	Airborne Relay Platform*
	1. Manned and Unmanned Aircraft
	2. Tethered Balloon
	3. High Altitude Powered Platform
IV.	Alternatives to Electromagnetic Communication Links
	1. Gravitational Waves
	2. Subnuclear Partical Beams

* Strictly speaking, airborne relay platforms are not transmission media but can be used to extend line-of-sight ranges. Investigation of such platforms has been specified in the Statement of Work of the DCS III study.

Table 2-2. Proposed Alternative Transmission Systems

SPECIFIED AREA	PROPOSED ALTERNATIVE SYSTEMS
Oahu Island, Hawaii	1. Millimeter Wave Relay System 2. Buried Cable System (Coaxial Cable or Optical Fiber)
Federal Republic of Germany	1. Airborne Communications System (Tethered Balloon or Aircraft) 2. Buried Cable System (Coaxial Cable or Fiber Optics)
Turkey	1. EHF Satellite 2. Airborne Relay System

System designs were prepared for each of the two alternatives in each area of interest, showing, nodes, links, path distances and number of channels and spares per link. Consideration was given to various network topologies (i.e. star, mesh.). Finally each media employed in an alternative was tailored to the environment and network requirements.

Task III generated a detailed review of rules, procedures, regulations, standards and recommendations established by international, regional and national organizations and agencies. These organizations include the International Telecommunications Union (ITU), International Radio Consultative Committee (CCIR), International Telegraph and Telephone Consultative Committee (CCITT) and U.S., German and Turkish civil and military national regulations.

This task also produced a detailed study of topographic and climatological study of the three regions under consideration. This study provides information relative to the placement of LOS terminals and repeaters as well as study of those attenuation factors such as rain and

snow that adversely affect millimeter wave transmission.

2.2 SUMMARY OF PHASE IB EFFORT

Task 1 identified three measures adopted by TRW to evaluate the system performance of a transmission media. Primarily, quality of channels is measured by bit error rate (BER). Secondly, time availability (TA) is measured by the percentage of time the quality of a channel is at least equal to or better than a specified BER. Finally, synchronization characteristics of the system are measured by Mean Time Between Loss of Bit Count Integrity (MLBCI).

Utilizing these three measures, a system performance evaluation methodology was devised for each of the media. These developed methodologies were then applied to the proposed transmission alternatives for performance comparison.

Quantitative data rates and link lengths were established, fade margin calculation parameters were determined for LOS systems, dispersion effect and power requirement quantification methods were determined for fiber optic systems and power budget calculation techniques established for satellite and relay systems.

The methodology developed may be applied to any communications systems; however, for purposes of this study, the methodology was applied to the two alternative networks proposed for each of the three areas of concern resulting in a comparative performance evaluation of the networks. Each network was evaluated in terms of BER, time available and synchronization characteristics.

Phase IB concluded with life-cycle cost projection of each alternative system under consideration. The following assumptions and ground rules were adopted prior to the costing exercise that apply in general to all networks regardless of media employed:

1. Cost estimates were made for transmission media only. Multiplexing and demultiplexing equipments, switching equipments were excluded in the cost estimates.
2. The multiplexing format of currently available and developing equipment such as AN/FCC-98 and AN/FCC-99 is assumed.

3. Acquisition costs include materials, initial spares, supporting test equipment, system engineering, purchasing, and program management costs necessary to acquire and ship the system components, and detail the installation criteria and instructions. Specifically not included were civil works (buildings, shelters, etc.), power generating equipment and Heating, Ventilating, and Air Conditioning (HVAC). It was assumed that all equipments and documentation are produced to best commercial standards.

4. Deployment costs include all labor and associated facilitating costs necessary for the installation, test, and cutover of the systems. These costs do not include acquisition of land, rights-of-ways, etc.

5. Initial development cost was applicable only if development is required and is unique to the candidate system.

6. "Spares consumption" includes calibration and maintenance costs of test and support equipment as well as replenishment of the initial spares complement.

7. "Operation and maintenance" costs include estimates of labor, and facilitating support, necessary to maintain normal communications requirements. Special procedures as might be necessary for extreme availability requirements were not accounted for. It was further assumed that operation and maintenance would be integrated into the existing support structure of the DCS.

8. Sustaining costs include "spares consumption" and "operation and maintenance." Other possible supporting costs, such as power and HVAC, are not included.

9. Life-cycle cost is simply total initial cost plus total sustaining cost for 10 years, using 1980 dollars with no inflation factor.

The system life-cycle cost of the six proposed transmission systems in the three areas of concern with dollar cost rounded to the nearest million is shown in Table 2-3.

Table 2-3. Transmission Alternative Systems Cost Summary (1980 Dollars, $ Million)

	HAWAII			CENTRAL GERMANY				TURKEY	
	Millimeter Wave LOS	Buried System		Airborne Relay		Buried System		EHF Satellite	Airborne Relay (Aircraft
		Optical Fiber	Coaxial Cable	Aircraft	Tethered Balloon	Optical Fiber	Coaxial Cable		
1980 Technology	41	17	72	88	85	52	131	75	119
2000 Technology	13	10	72	65	67	34	131	49	85

2.3 IMPACT OF PHASE I EFFORT

The results of the Phase I effort were utilized by DCEC to provide guidance for this Phase II effort as stated in Section 1.2.

Major changes in the scope of the Phase II of DCS III study include the elimination of the sparsely populated Turkish area from consideration and the consideration only of microwave, millimeter wave and optical fiber transmission media for utilization in the German and Hawaiian areas.

The proposed manned aircraft as an alternative for the Turkish area proved to be too costly to implement due to the need for two relay points, aircraft endurance, flying crew fatigue and logistics support. The other Turkish alternative proposed an EHF satellite system which while performing satisfactorily at about one-half the life cycle cost of the manned aircraft, however EHF satellite has been studied intensively elsewhere and also was eliminated from further Phase II consideration. Thus, the Phase II effort was directed to eliminate consideration of Turkey and concentrate only on the German and Hawaiian areas.

Coaxial cable transmission evaluated for use in Hawaii and Germany was discarded as a suitable media for the Phase II effort in favor of optical fiber cable transmission. This decision was based on the wide disparity in cost between the two buried cable media. Although both media exhibit performance characteristics adequate for DCS III needs, in terms of 1980 technology, fiber optic implementation costs were found to be only 24% of coaxial cable cost, and in terms of anticipated year 2000 technological advances in fiber optic implementation was projected as only 14%.

The tethered balloon relay evaluated as one of the alternatives for German implementation was eliminated from further consideration as it was found to be bulky and subject to sabotage.

The Phase I study clearly indicates that only microwave, millimeter wave and optical fiber media should be considered as implementing media for the Phase II study. Use of these media either singly or in combination, utilizing either a Government-owned or a commercial lease environment provides the basis of the Phase II study.

2.4 SUMMARY OF PHASE II TASK 1 EFFORT

The major effort of Phase II Task 1 of DCS III Study is the following:

- RF transmission model development including microwave LOS system, millimeter wave LOS system, and fiber optic system
- Link design methodology development for the above mentioned transmission media
- Design transmission alternatives for Oahu Island, Hawaii, including microwave LOS system, millimeter wave LOS system, and fiber optic system
- Design transmission alternatives for Central Germany, consisting of microwave LOS system, millimeter wave LOS system, microwave and millimeter wave mix I and II.
- Quantative review of leased common carrier for Hawaii and cost sharing fiber optic for Central Germany
- Overlay wideband user requirements on the transmission alternatives design -- all alternatives designed for both common user's and wideband user's requirements.

The present report is not intended to be a stand alone one, therefore, a complete summary of the Phase II Task 1 Report (Ref. 1-3) will not be provided here. Instead of that, only a brief account of a few selected topics which are deemed as necessary background material for this report are given in this section. These topics are multiplexer and demultiplexer, RF system models, and transmission alternatives designs.

2.4.1 Multiplexer and Demultiplexer

Multiplexers and demultiplexers are a necessary part of a communications system but, physically, they form an independent unit separated from RF transmission equipment. Multiplexers and demultiplexers are not considered in the present DCS III Study since the major concern of this study is RF transmission media. For RF model development and link design, signal format, information bit rate, mission bit rate, transmission bandwidth, etc. must be established; therefore the modulation scheme has to be

specified. It has been stated in previous reports that the FCC-98 and Fcc-99 multiplexer/demultiplexer formats are assumed to continue in use. However, for DCS III transmission alternative design, a high level multiplexer/demultiplexer is needed and has been proposed and employed. This scheme has not yet been explicitly stated in Phase II Task 1 report and is presented below.

This proposed scheme is shown in Figure 2-1. The first level multiplexer/demultiplexer is FCC-98 which combines 24 voice channels, 64 kbps each, to form a 1.544 Mbps bit stream. This is the current North American Standard (Bell System Level DS1), often called T1 which is the same as that of recommendation of C 733 of CCITT. Each 64 kbps digital voice can accommodate data at various lower bit rates. High digital data streams (128, 256, 512 kbps) can be accommodated by using two or more 64 kbps channels.

The military standard second level multiplexer, FCC-99, accepts up to eight FCC-98 bit streams and produces a composite mission bit stream. It also accommodates higher digital data rates of 3.088 and 6.176 Mbps in place of two and four 1.544 Mbps parts respectively. The output mission bit stream rates are 3.232, 6.464, 9.696, and 12.928 Mbps, and the two lower rates are for two port and four port strapping operations.

Note that the military level two mission bit rate of 12.928 Mbps is different from the Northern American (Bell System) and Japanese Standard bit rate of 6.312 Mbps or the CEPT standard rate of 8.448 Mbps. The third level standard bit rate of these standards are 44.736, 32.064, and 34.368 Mbps respectively.

For the developed RF transmission models, documented in Section 4 of Phase II Task 1 Report (Ref. 1-3) and briefly tabulated in the following Section 2.4.2, assumption has been made that a modulator or transmitter can accept either up to four FCC-99 mission bit streams plus a service/alarm/control bit stream up to 384 kpbs, or a bit stream of a third level multiplexer with a bit rate of 52.096 Mbps or higher.

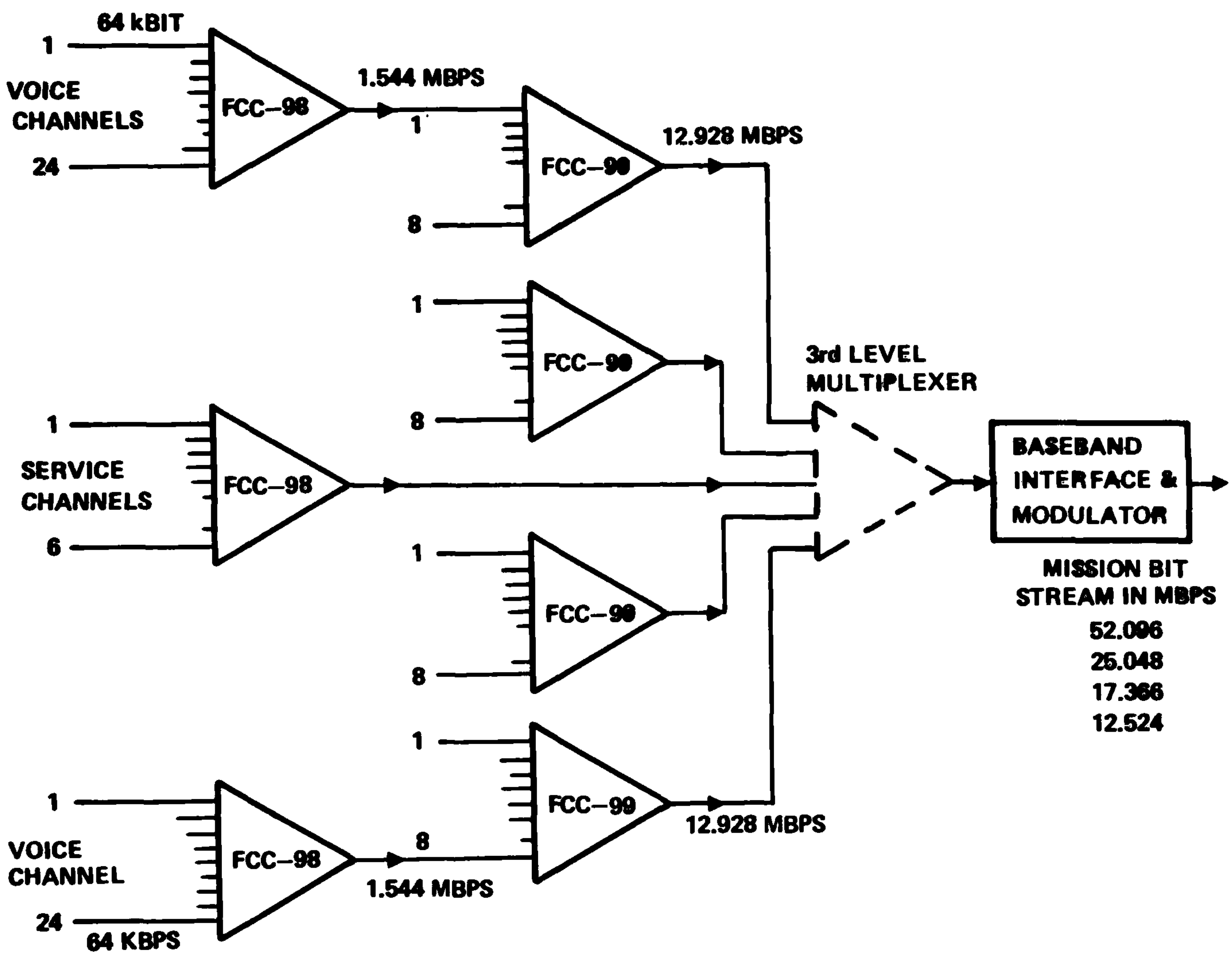

Figure 2-1. Proposed Multiplexer/Demultiplexer Scheme

The number of ports with input data rate up to 12.928 Mbps of the third level multiplexer is not yet defined. As shown in Figure 2-1, it should be capable of accommodating at least four level two multiplexers (FCC-99) and a level one multiplexer (FCC-98). The mission transmission bit rates of 52.096, 25.048, 17.366 and 12.524 Mbps are indicated in Figure 2-1. These rates correspond to a transmitter employing a modulation scheme with efficiency of 1, 2, 3, or 4 bps/Hz.

2.4.2 RF Transmission System Models

Three RF transmission models, microwave LOS system, millimeter wave LOS system, and fiber optic system, have been developed in Phase II Task 1. Detailed system description is presented in Phase II Task 1 Final Report (Ref. 1-3). For ready reference, brief specifications of these developed models are presented in the following Table 2-4, 2-5, and 2-6.

2.4.3 Transmission Alternatives Design

Preliminary transmission alternative designs for Oahu Island, Hawaii and Central Germany have been made for both common user and wideband user and presented in Sections 6 and 7, respectively, of Phase II Task 1 Report (Ref. 1-3).

These alternative designs have been reviewed and modified during the Task 2 performance period. Two designs were made for each alternative; one called minimum network and the other proposed network. The minimum network design is the bare necessity to fullfil the traffic requirement. The proposed network is a slightly modified version of the corresponding minimum network either providing more spare capacity for some selected links or adding a few redundant links, or both for the important nodes and major links of the network.

Both the minimum and proposed network for each alternative are shown here by a network topological map and link traffic capacity table. For related information, the reader is referred to Sections 6 and 7 of Reference 1-3.

TABLE 2-4. SPECIFICATION OF MICROWAVE LOS SYSTEM

<u>Transmitter</u>	
RF Power Output	2 Watts
Emission Bandwidth	14 MHz
Frequency	8 GHZ
Frequency Stability	$\pm$.0005% 0°C to 40°C
Modulation	16 Level QAM
<u>Receiver</u>	
Noise Figure	5 dB
S/N at 10^{-9} BER	24 dB
Dynamic Range Threshold 10^{-6} BER	-68 dBm
10^{-3} BER	-72 dBm
<u>*Data Interface Characteristics*</u>	
Channel Capacity	768 Voice Channels
Transmission Bit Rate	52.096 Mbps $\pm$ 20 ppm
Frequency Utilization Efficiency	4 bps/Hz
Data Streams	Bipolar, B3ZS
Auxiliary Channels	384 kbps
Impedance	75 ohm $\pm$ 5%
Power Level	-1.8 to + 5.7 dBm
<u>Power</u>	
Input Voltage	-24/48 vdc
Terminal Current Consumption	40/20 AMP
Repeater Current Consumption	70/35 AMP

TABLE 2-4. SPECIFICATION OF MICROWAVE LOS SYSTEM (CONTINUED)

Operating Environment	
Temperature	0° to 49° C
Altitude	0 to 4572 m
Humidity	0 to 95%
EMI	MIL-STD-461
Physical Characteristics	
Terminal	521 X 225 X 2133 mm
	70 Kg
Repeater	1042 X 225 X 2133 mm
	140 Kg

Alarm Upon occurence of any one or more of the following malfunctions or conditions, an alarm will be reported at both terminals.

Transmitter:	Receiver:
All input data/timing	All output data/timing
Buffer overflow/underflow	Buffer overflow/underflow
Modulation output	Demodulator output
Oscillator frequency drift	Frame sync loss
Output power	Low frame BER
Online/offline status	Oscillator frequency drift
External/internal timing	Online/offline status

Power Supply Voltage Level

TABLE 2-5. SPECIFICATION OF A MILLIMETER WAVE LOS SYSTEM

Transmitter	
RF Power Output	2 Watts
Emission Bandwidth	17.4 MHz
Frequency	36 GHz
Modulation	8 PSK
Receiver	
Noise Figure	5 dB
S/N at 10^{-9} BER	21.5 dB
Threshold 10^{-3} BER	-77.3 dBm
Data Interface	
Channel Capacity	768 Voice Channels
Transmission Bit Rate	51.712 Mbps $\pm$ 20 ppm
Frequency Utilization Efficiency	3 bps/Hz
Data Stream	Bipolar, B3ZS
Auxiliary Channels	384 kbps
Power Level	-1.8 to + 5.7 dBm
Power Supply	
Voltage	-24/48 vdc
Consumption	50 Watts

TABLE 2-5. SPECIFICATION OF A MILLIMETER WAVE LOS SYSTEM (CONTINUED)

Operating Environment	
Temperature	0° to 50° C
Altitude	0 to 4572 m
Humidity	0% to 95%
EMI	MIL-STD-461
Physical Characteristics	
Weight	25 kg
Alarm Upon occurence of any one or more of the following malfunctions or conditions, an alarm will be reported at both terminals.	
Transmitter:	Receiver:
All input data/timing	All output data/timing
Buffer overflow/underflow	Buffer overflow/underflow
Modulation output	Demodulator output
Oscillator frequency drift	Frame sync loss
Output power	Low frame BER
Online/offline status	Oscillator frequency drift
External/internal timing	Online/offline status
Power Supply Voltage Level	

TABLE 2-6. SPECIFICATION OF AN OPTICAL FIBER SYSTEM

<u>Interface Specifications</u>	
Data Rate	52.096 Mbps ± 20 ppm
Line Code	Bipolar, B3ZS
Line Impedance	75 ohms ± 5% unbalanced
Power Level	-1.8 to + 5.7 dBm
<u>Optical Interface</u>	
Transmit Power Output	0 dBm
Receiver Input for 10^{-9} BER	-45 dBm
Fiber Type	Single mode-step index
<u>Optical Source Specifications</u>	
Duty Cycle	100%
Peak Emission Wavelength	1.3 μm
Spectral Linewidth (1/2 peak)	1 nm
Rise Time	.7 ns
Output Power	10 mW
Modulation Rate	1 Gbps
Mode Pattern	Single Mode
Quantum Efficiency	60%
Beam Divergence	45° Vertical 9° Horizontal
<u>Optical Detector Specifications</u>	
Spectral Response	300 GHz
Peak Response	1.3 μm
Responsitivity	60 A/W

TABLE 2-6. SPECIFICATION OF AN OPTICAL FIBER SYSTEM (CONTINUED)

Fiber Specifications Optical			
Region of Zero Dispersion	1.3 μm		
Maximum Attenuation	.5 dB/km at 1.3 μm		
Bandwidth Fiber Length Product	20 Gbps-km		
Nominal Numerical Aperture	.2		
Splice Loss	0.5 dB		
Connector Loss	0.5 dB		
Mechanical			
	GENERAL PURPOSE	HEAVY DUTY UNSHEATHED	HEAVY DUTY SHEATHED
Jacketed Fiber Diameter (mm)	0.5	1.0	1.0
Cable Diameter (mm)	6.1	7.0	9.7
Weight (kg/km)	30	39	58
Minimum Bend Radius (cm)	4	5	10
Short-Term Tensile Strength (kgf)	150	150	150
Maximum Number of Fibers Per Cable	12	12	12
Power Requirements			
Switch	250 watts, 48 Vdc.		
Fiber Optic Terminal	75 watts, 48 Vdc.		
Environmental Specifications			
Temperature	0° C to 50°		
Humidity	95°		
Altitude	500 meters		

The performance evaluation under stressed conditions and life cycle cost estimation made for each alternative are based on the proposed network. The minimum network information is provided here for reference.

Figures 2-2 to 2-13 inclusive are the network topological maps of the minimum and proposed network for each alternatives. Table 2-7 to 2-18 inclusive are link capacity for both networks for each alternatives.

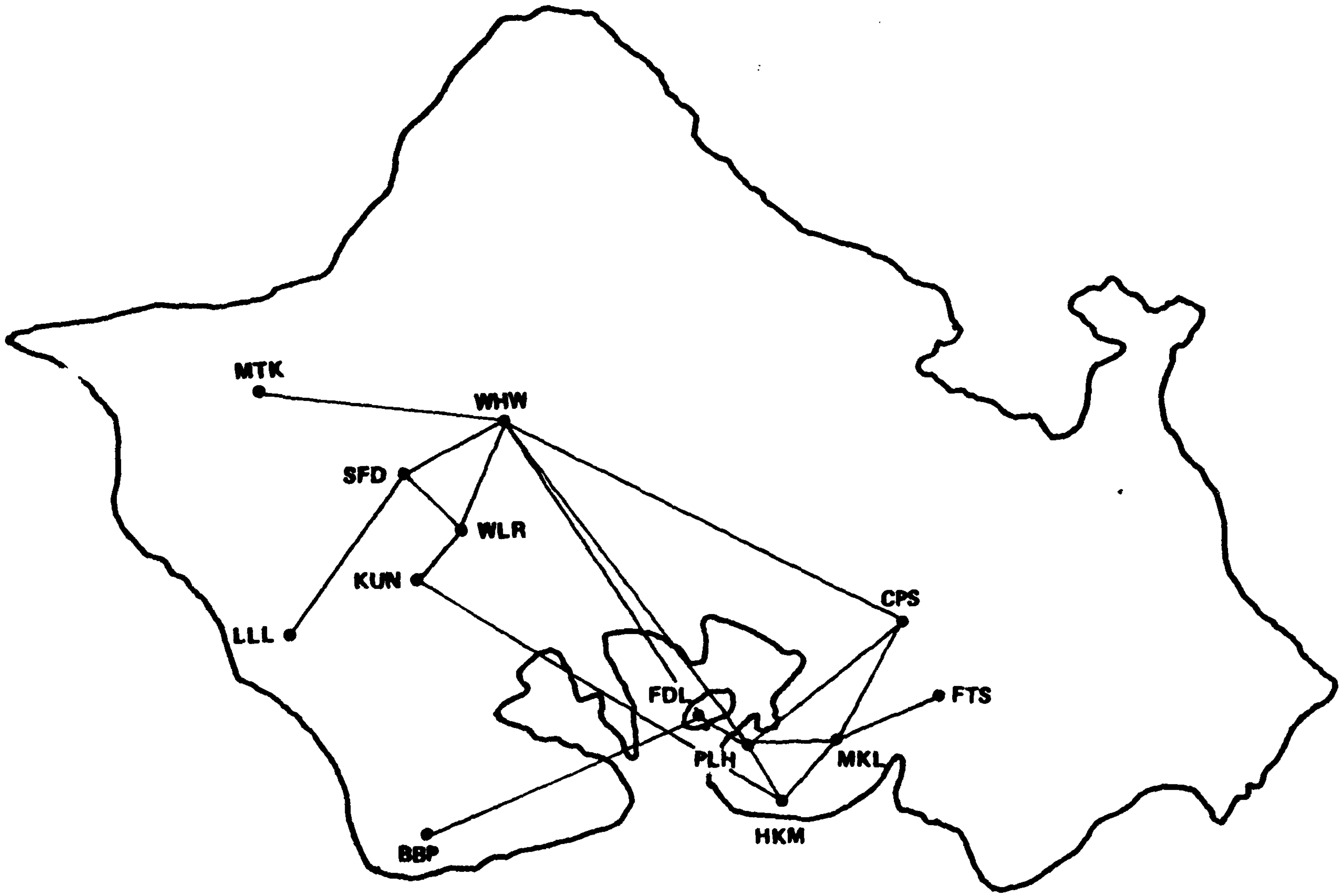

Figure 2-2. Minimum Microwave and Millimeter Wave LOS Network for Oahu, Hawaii

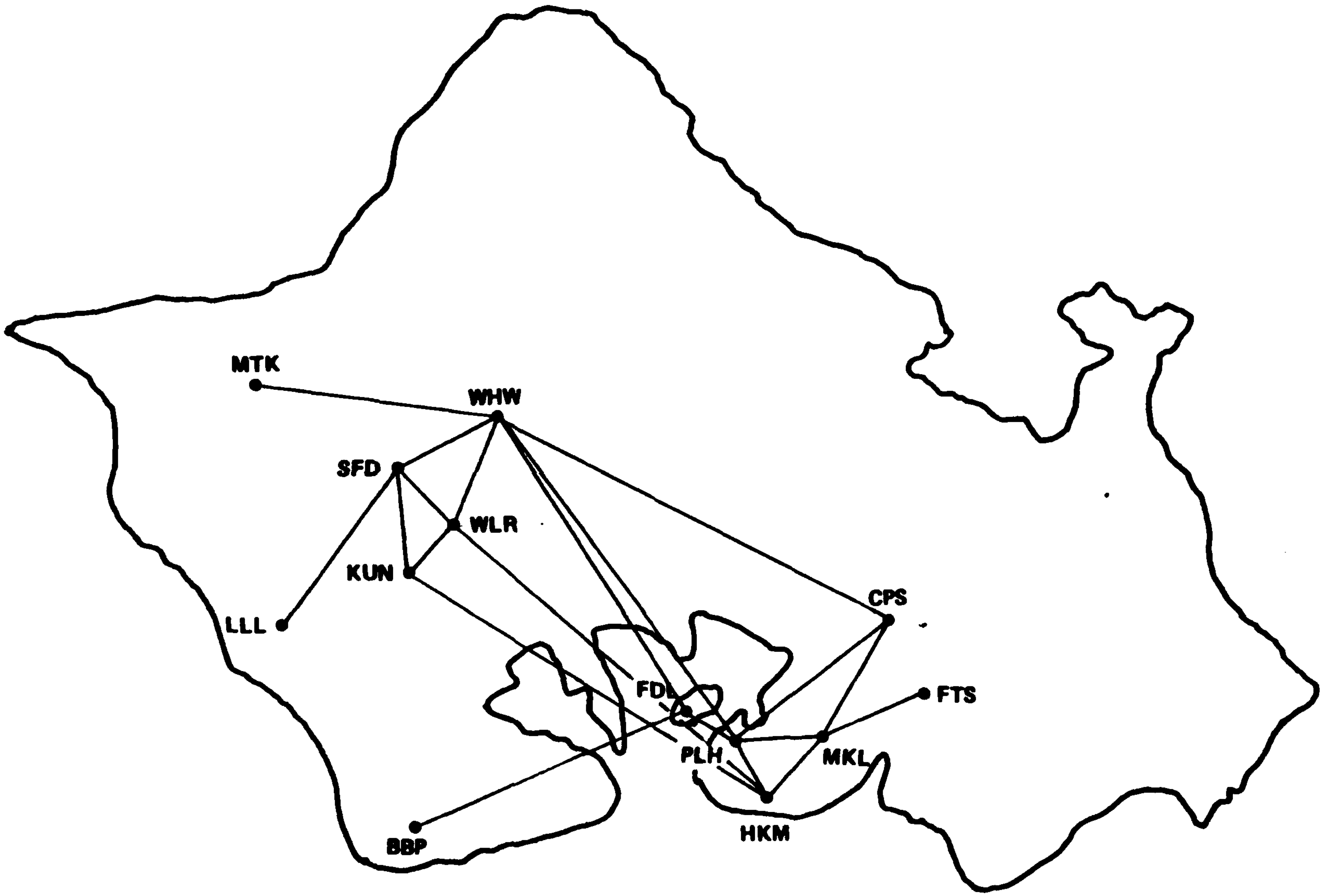

Figure 2-3. Proposed Microwave and Millimeter Wave LOS Network for Oahu, Hawaii

Table 2-7. MINIMUM MICROWAVE AND MILLIMETER WAVE LOS NETWORK FOR OAHU, HAWAII

No.	Link	Channel * Capacity
1	MTK-WHW	6/2
2	LLL-SFD	6/2
3	SFD-WHW	12.5/3.5 + 20
4	WHW-WLR	19/5 + 10
5	KUN-WLR	12.5/3.5 + 10
6	WLR-SFD	0/0 + 10
7	KUN-HKM	8/2
8	BBP-FDL	12.5/3.5
9	PLH-CPS	6/2 + 10
10	CPS-MKL	12.5/3.5
11	PLH-MKL	19/5
12	FTS-MKL	12.5/3.5
13	MKL-HKM	6/2
14	WHW-PLH	19/5 + 30
15	FDL-PLH	6/2 + 10
16	PLH-HKM	19/5 + 10
17	WHW-FDL	12.5/3.5 + 10
18	WHW-CPS	6/2 + 10

Table 2-8. PROPOSED MICROWAVE AND MILLIMETER WAVE LOS NETWORK FOR OAHU, HAWAII

No.	Link	Channel * Capacity
6	WLR-SFD	0/8 + 10
19	KUN-SFD	0/8
20	WLR-HKM	0/8

** Notes apply to all following tables for proposed network

Proposed network consists of three groups of links

1. Links of the minimum network with link capacity changed listed in the proposed network table
2. All other links of the minimum network without changes not listed in the proposed network table
3. Additional links listed in the proposed network table

Configuration and link capacity of minimum/proposed microwave LOS network and minimum/proposed millimeter wave LOS network are identical respectively.

* Notes apply to all following tables

- The channel capacity of each link is given in terms of number of T1 channels for traffic/spare for common user requirement
- The second entries of some links are wideband user's requirement in terms of Mbps. There are two alternate routes for each requirement.

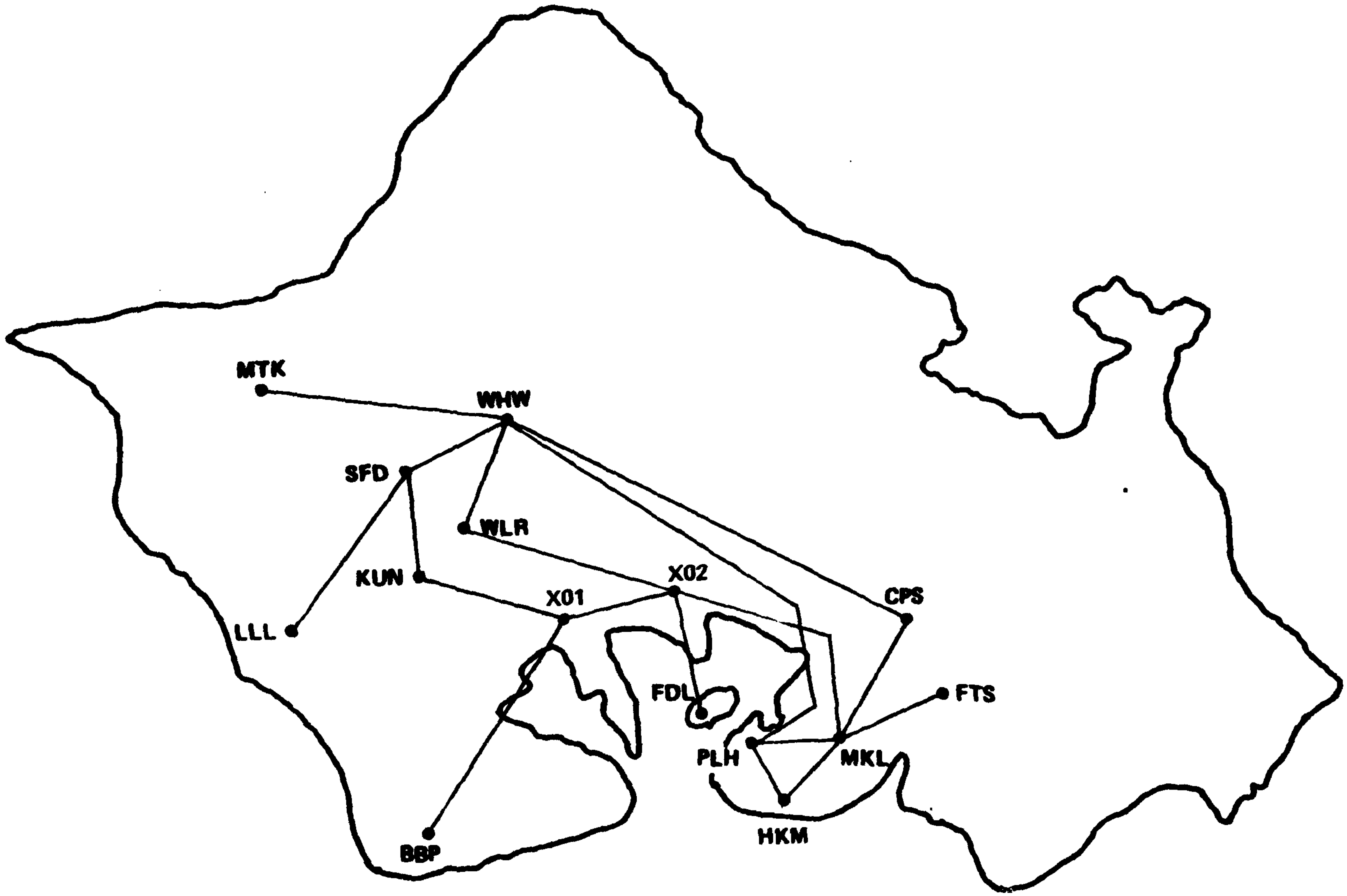

Figure 2-4. Minimum Fiber Optics Network for Oahu, Hawaii

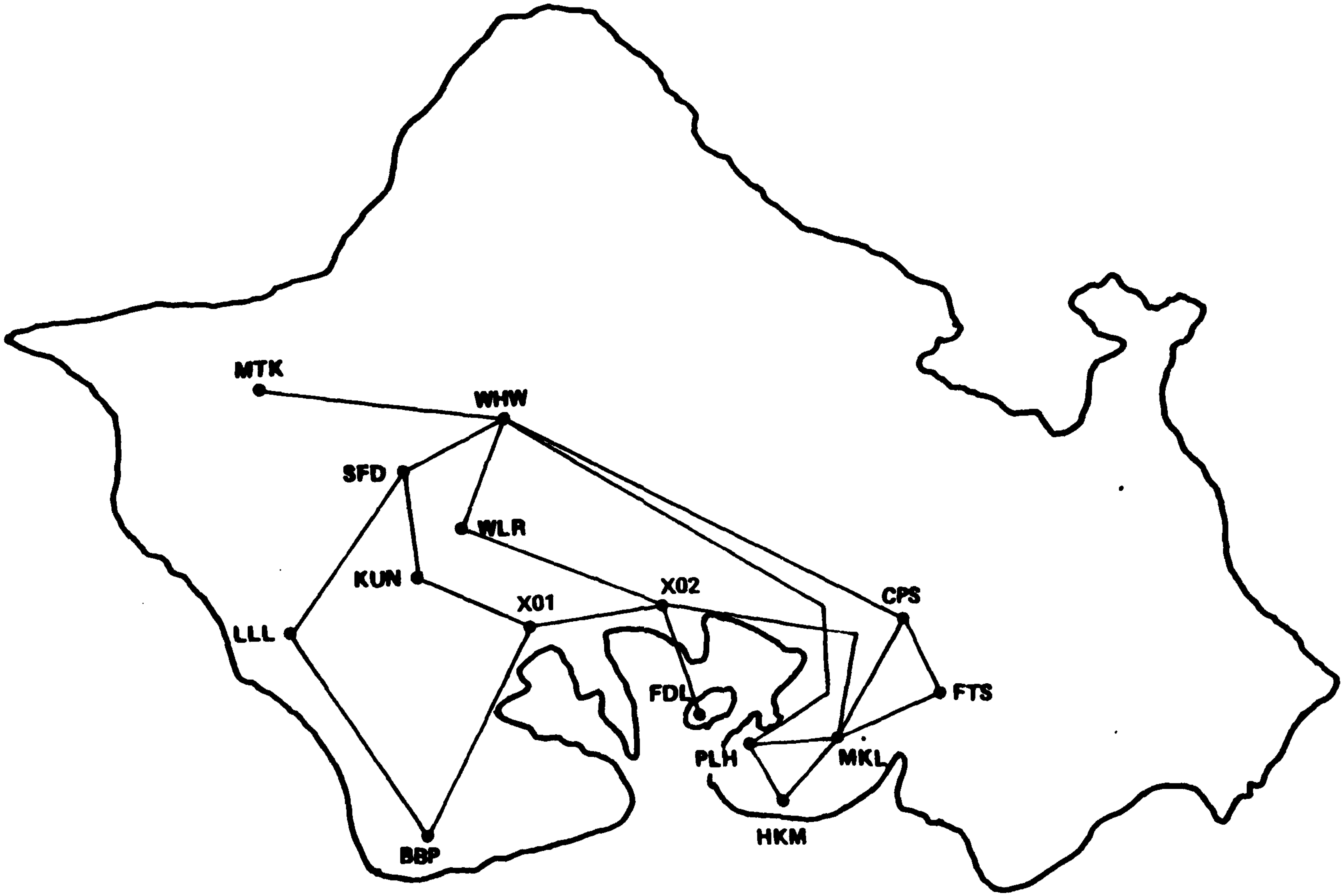

Figure 2-5. Proposed Fiber Optics Network for Oahu, Hawaii

Table 2-9. MINIMUM FIBER OPTIC NETWORK FOR OAHU, HAWAII

No.	Link	Channel * Capacity
1	MTK-WHW	6/2
2	SFD-WHW	12.5/3.5 + 10
3	WHW-WLR	25.5/6.5 + 30
4	SFD-KUN	12.5/3.5
5	SFD-LLL	6/2
6	BBP-X01	12.5/3.5
7	KUN-X01	6/2
8	WLR-X02	6/2 + 20
9	X02-MKL	6/2 + 20
10	CPS-MKL	25.5/6.5 + 20
11	FTS-MKL	12.5/3.5
12	MKL-PLH	19/5 + 10
13	MKL-HKM	12.5/3.5 + 10
14	HKM-PLH	19/5 + 10
15	X02-FDL	19/5
16	X01-X02	19/5
17	WHW-PLH	19/5 + 20
18	WHW-CPS	12.5/3.5 + 20
19	SFD-WLR	12.5/3.5 + 10

Table 2-10. PROPOSED FIBER OPTIC ** NETWORK FOR OAHU, HAWAII

No.	Link	Channel Capacity
20	LLL-BBP	0/8
21	CPS-FTS	0/8

* See Note of Table 2-7

** See Note of Table 2-8

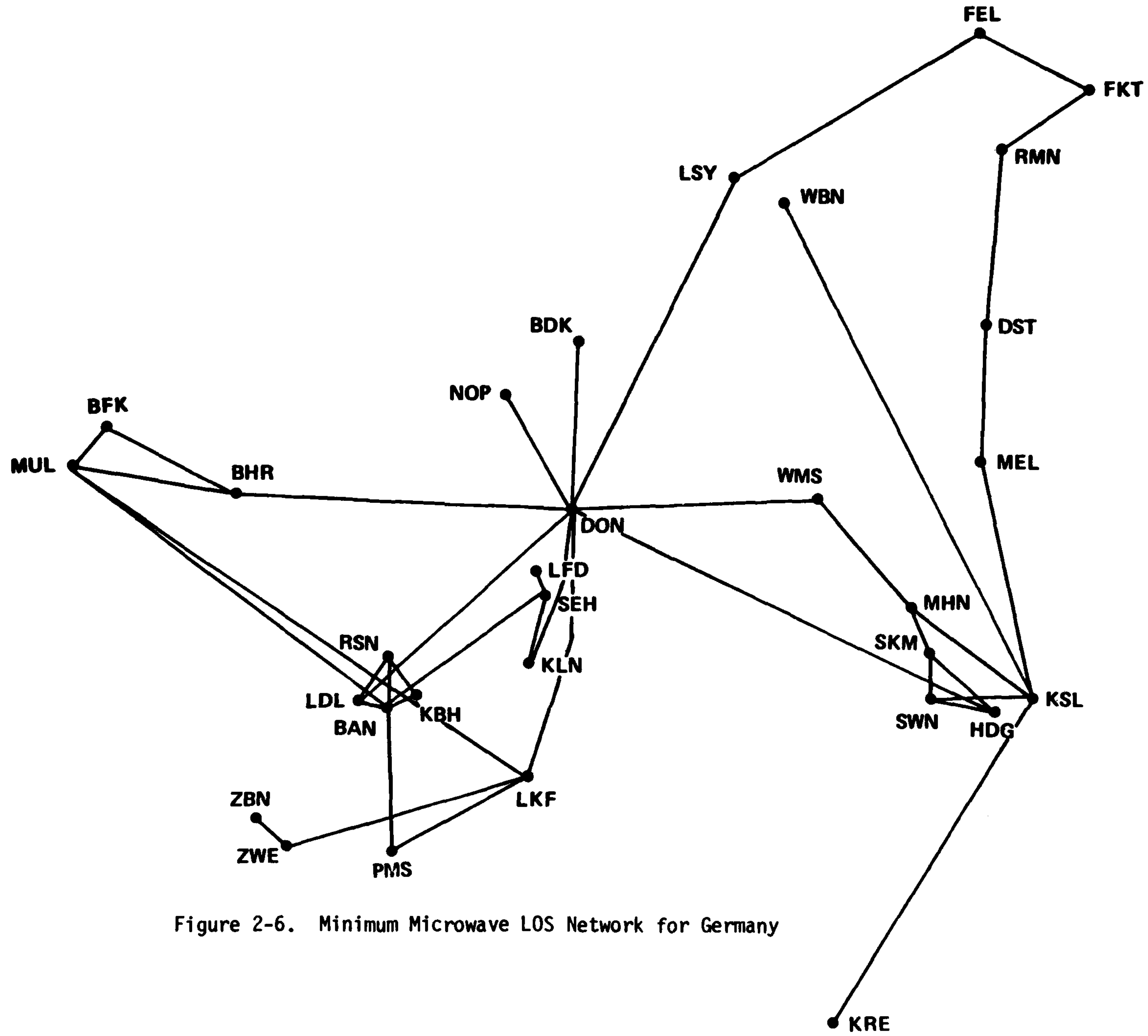

Figure 2-6. Minimum Microwave LOS Network for Germany

Table 2-11. Minimum Microwave Network for Germany

No.	Link	Channel*	No.	Link	Channel*
1	BAN-KBH	5/1	21	FKT-LSY	0/0 + 10
2	BAN-LDL	5.5/1.5 + 30	22	HDG-SKM	5/1 + 10
3	BAN-MUL	12.5/2.5 + 10	23	HDG-SWN	12.5/2.5
4	BAN-PMS	13/3	24	KBH-RSN	5/1
5	BAN-RSN	12.5/2.5 + 10	25	KLN-SEH	8/2 + 20
6	BAN-SEH	13/3 + 20	26	KRE-KSL	3/1
7	BDK-DON	2.5/.5	27	KSL-MEL	4/1 + 10
8	BFK-BHR	0/0 + 10	28	KSL-MHN	5.5/1.5 + 10
9	BFK-MUL	5.5/1.5 + 10	29	KSL-SWN	5.5/1.5
10	BHR-DON	9/2 + 10	30	KSL-WBN	1.5/.5
11	BHR-MUL	7.5/1.5	31	LDL-RSN	6.5/1.5 + 10
12	DON-HDG	10/2 + 10	32	LFD-SEH	1/.5
13	DON-KLN	13/3 +10	33	LKF-MUL	9/2
14	DON-LDL	13/3 + 20	34	LKF-PMS	11/2.5
15	DON-LKF	8.5/2	35	LKF-ZWE	5/1
16	DON-LSY	2.5/.5 + 10	36	MHN-SKM	5/1 + 10
17	DON-NOP	1.5/.5	37	MHN-WMS	4.5/1 + 10
18	DON-WMS	4/1 + 10	38	SKM-SWN	5/1
19	DST-FKT	0/0 + 10	39	ZBN-ZWE	4/1
20	DST-MEL	2.5/.5 + 10			

* See note of Table 2-7

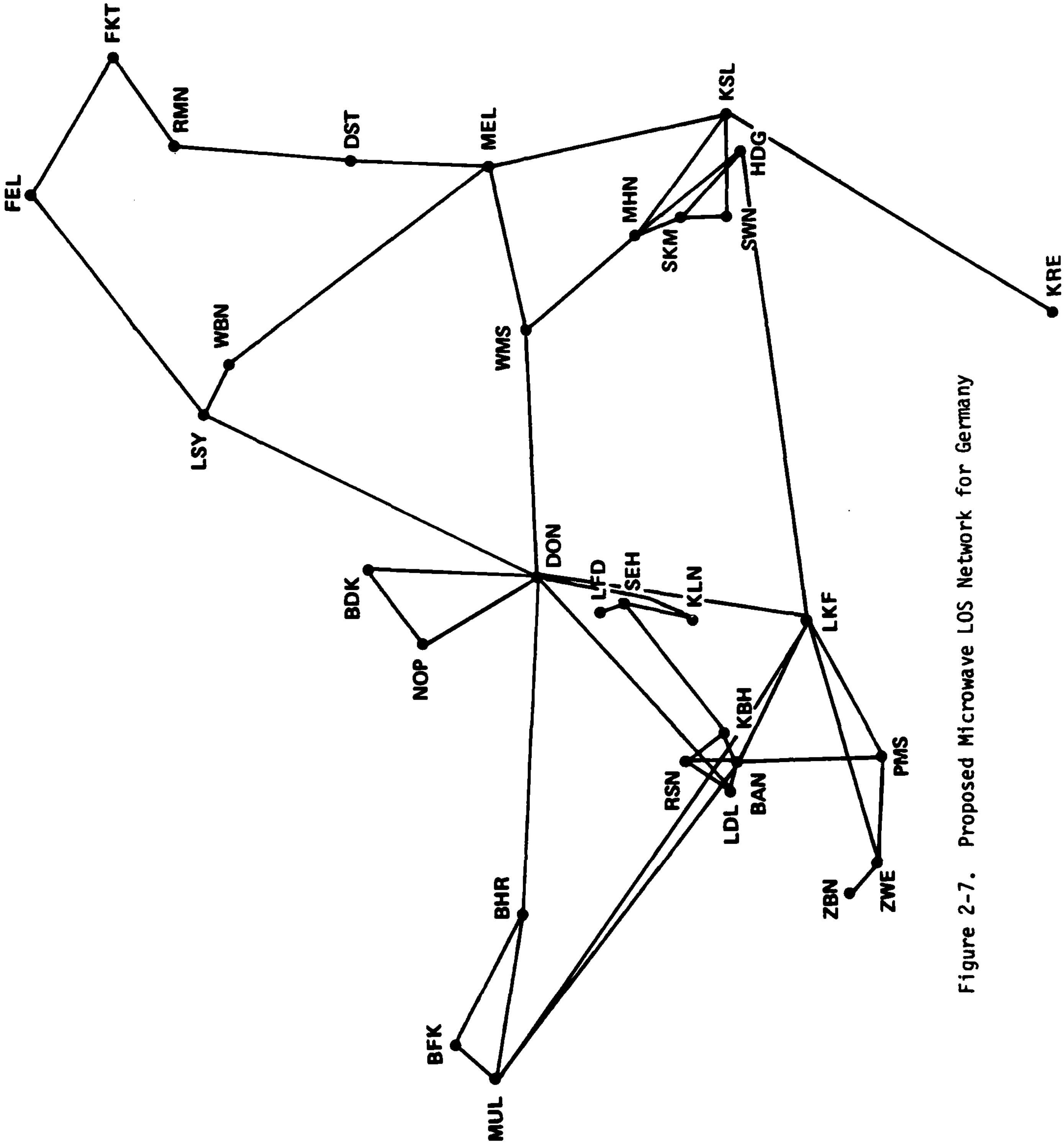

Figure 2-7. Proposed Microwave LOS Network for Germany

Table 2-12. Proposed Microwave Network for Germany**

No.	Link	Channel*	No.	Link	Channel*
6	BAN-SEH	13/8 + 20	19	DST-FKT	0/2 + 10
8	BFK-BHR	0/4 + 10	21	FKT-LSY	0/2 + 10
9	BFK-MUL	5.5/4.5 + 10	22	HDG-SKM	5/1
12	DON-HDG	Delete	25	KLN-SEH	8/8 + 20
13	DON-KLN	13/6 + 10	30	KSL-WBN	Delete
15	DON-LKF	18.5/6	34	LKF-PMS	11/5
16	DON-LSY	2.5/2.5 + 10	35	LKF-ZWE	5/5
17	DON-NOP	1.5/1.5	36	MHN-SKM	5/1
18	DON-WMS	4/3 + 10			
40	BAN-LKF	0/2 + 10	44	LSY-WBN	0/2
41	BDK-NOP	0/2	45	MEL-WBN	0/2
42	HDG-LKF	8.5/6 + 10	46	MEL-WMS	0/3 + 10
43	HDG-MHN	0/3 + 10	47	PMS-ZWE	0/5

* See note of Table 2-7

** See note of Table 2-8

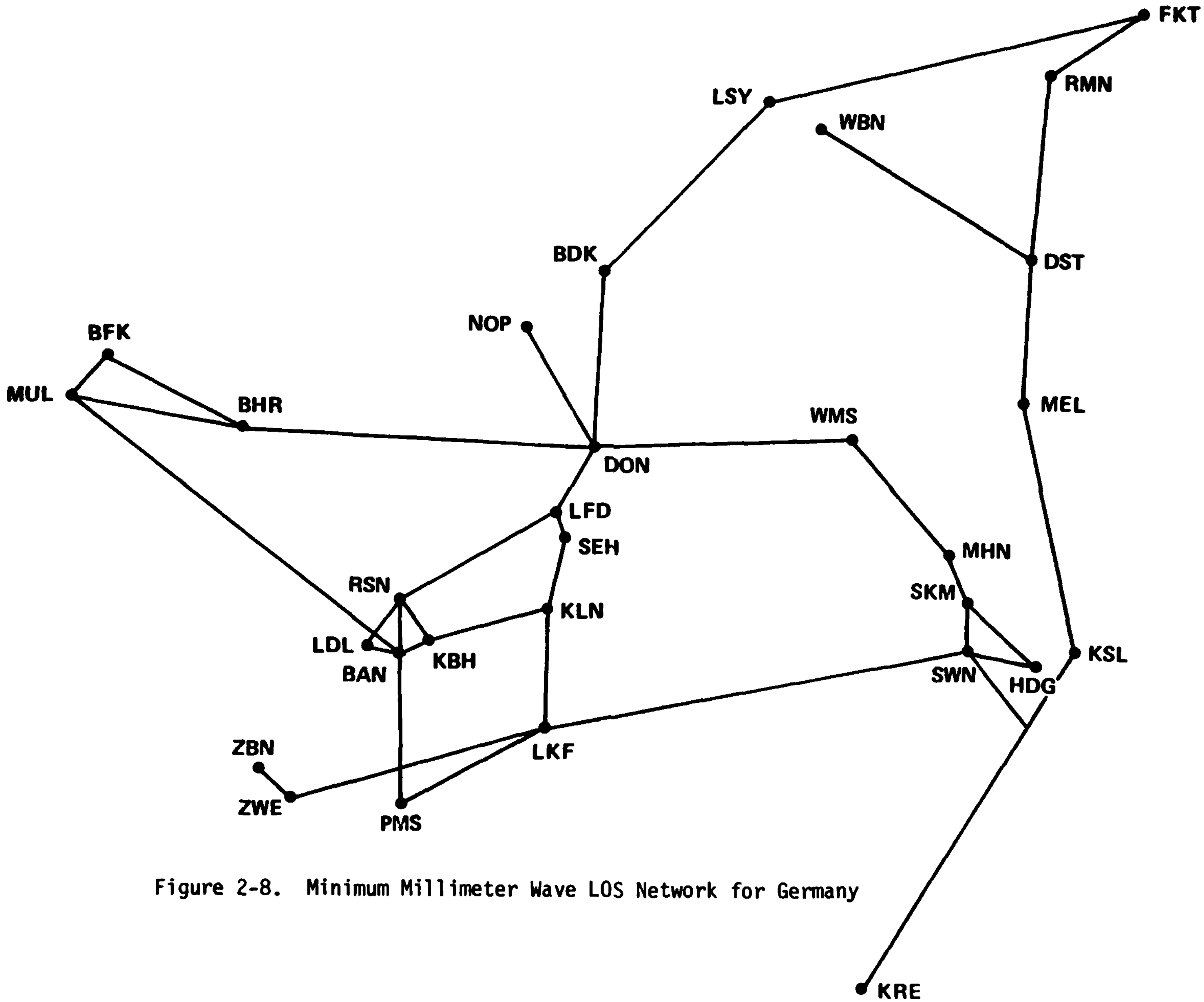

Figure 2-8. Minimum Millimeter Wave LOS Network for Germany

Table 2-13. Minimum Millimeter Wave Network for Germany

No.	Link	Channel*	No.	Link	Channel*
1	BAN-KBH	14/3 + 20	20	HDG-SWN	12.5/2.5 + 10
2	BAN-LDL	5.5/1.5 + 30	21	KBH-KLN	22/4.5 + 20
3	BAN-MUL	21.5/4.5 + 10	22	KBH-RSN	5/1
4	BAN-PMS	13/3	23	KLN-LKF	17.5/4 + 20
5	BAN-RSN	12.5/2.5 + 10	24	KLN-SEH	21/4.5
6	BDK-DON	5/1 + 10	25	KRE-KSL	3/1
7	BDK-LSY	2.5/.5 + 10	26	KSL-MEL	5.5/1.5
8	BFK-BHR	0/2 + 10	27	KSL-SWN	11/2.5
9	BFK-MUL	5.5/1.5 + 10	28	LDL-RSN	19.5/4 + 20
10	BHR-DON	9/2 + 10	29	LFD-RSN	13/3 + 20
11	BHR-MUL	7.5/1.5	30	LFD-SEH	22.5/4.5
12	DON-LFD	34.5/7 + 30	31	LKF-PMS	11/2.5
13	DON-NOP	1.5/.5	32	LKF-SWN	0/4 + 10
14	DON-WMS	14/3 + 10	33	LKF-ZWE	5/1
15	DST-FKT	0/0 + 10	34	MEL-WMS	0/4 + 10
16	DST-MEL	4/2 + 10	35	MHN-SKM	20.5/4.5+ 10
17	DST-WBN	1.5/.5	36	MHN-WMS	14.5/3 + 10
18	FKT-LSY	0/0 + 10	37	SKM-SWN	10.5/2.5
19	HDG-SKM	20.5/4.5 + 10	38	ZBN-ZWE	4/1

* See note of Table 2-7

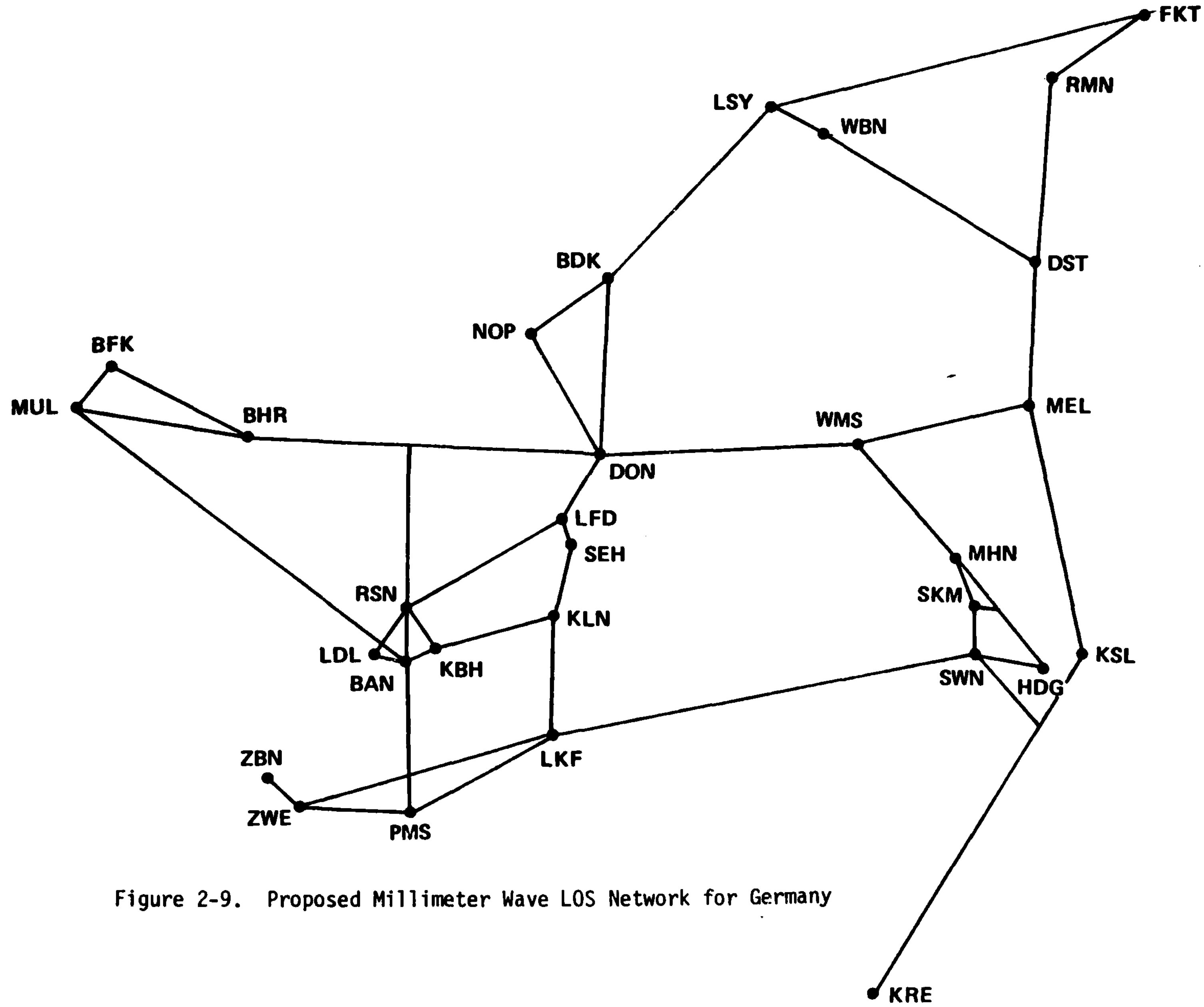

Figure 2-9. Proposed Millimeter Wave LOS Network for Germany

Table 2-14. Proposed Millimeter Wave Network for Germany**

No.	Link	Channel*	No.	Link	Channel*
10	BHR-DON	9/2	29	LFD-RSN	13/3 + 10
11	DON-LFD	34.5/7 + 20			
39	BDK-NOP	0/2	42	LSY-WBN	0/2
40	BHR-RSN	0/4 + 10	43	PMS-ZWE	0/5
41	HDG-MHN	0/1 + 10			

* See note of Table 2-7

** See note of Table 2-8

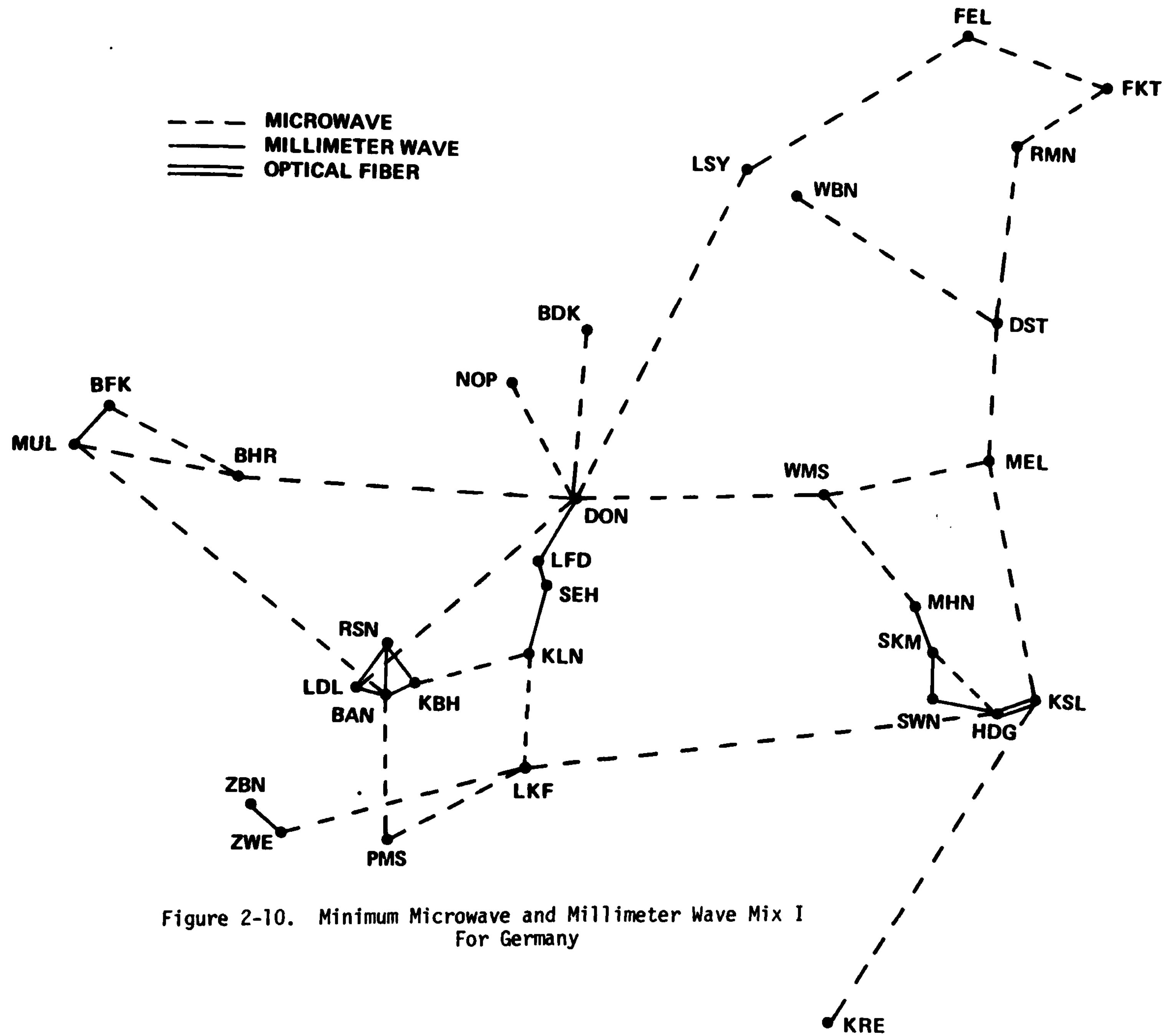

Figure 2-10. Minimum Microwave and Millimeter Wave Mix I For Germany

Table 2-15. Minimum Microwave and Millimeter Wave Mix I

No.	Link	Channel*	No.	Link	Channel*
1	BAN-KBH	5/1 + 20	21	HDG-KSL	11/2.5
2	BAN-LDL	5.5/1.5 + 30	22	HDG-LKF	0/2 + 10
3	BAN-LKF	9/2 + 10	23	HDG-SKM	20.5/4.5 + 10
4	BAN-MUL	21.5/4.5 + 10	24	HDG-SWN	12.5/2.5 + 10
5	BAN-PMS	13/3	25	KBH-KLN	13/3 + 20
6	BAN-RSN	12.5/2.5 + 10	26	KBH-RSN	5/1
7	BDK-DON	2.5/.5	27	KLN-LKF	8.5/2
8	BFK-BHR	0/2 + 10	28	KLN-SEH	29.5/6 + 20
9	BFK-MUL	5.5/1.5 + 10	29	KRE-KSL	3/1
10	BHR-DON	9/2 + 10	30	KSL-MEL	5.5/1.5
11	BHR-MUL	7.5/1.5	31	LDL-RSN	6.5/1.5 + 10
12	DON-LDL	13/3 + 20	32	LFD-SEH	22.5/4.5 + 20
13	DON-LFD	21.5/4.5 + 20	33	LKF-PMS	11/2.5
14	DON-LSY	2.5/.5 + 10	34	LKF-ZWE	5/1
15	DON-NOP	1.5/.5	35	MEL-WMS	0/2 + 10
16	DON-WMS	14/3 + 10	36	MHN-SKM	20.5/4.5 + 10
17	DST-FKT	0/0 + 10	37	MHN-WMS	14.5/3 + 10
18	DST-MEL	4/1 + 10	38	SKM-SWN	15/3 + 10
19	DST-WBN	1.5/.5	39	ZBN-ZWE	4/1
20	FKT-LSY	0/0 + 10			

* See note of Table 2-7

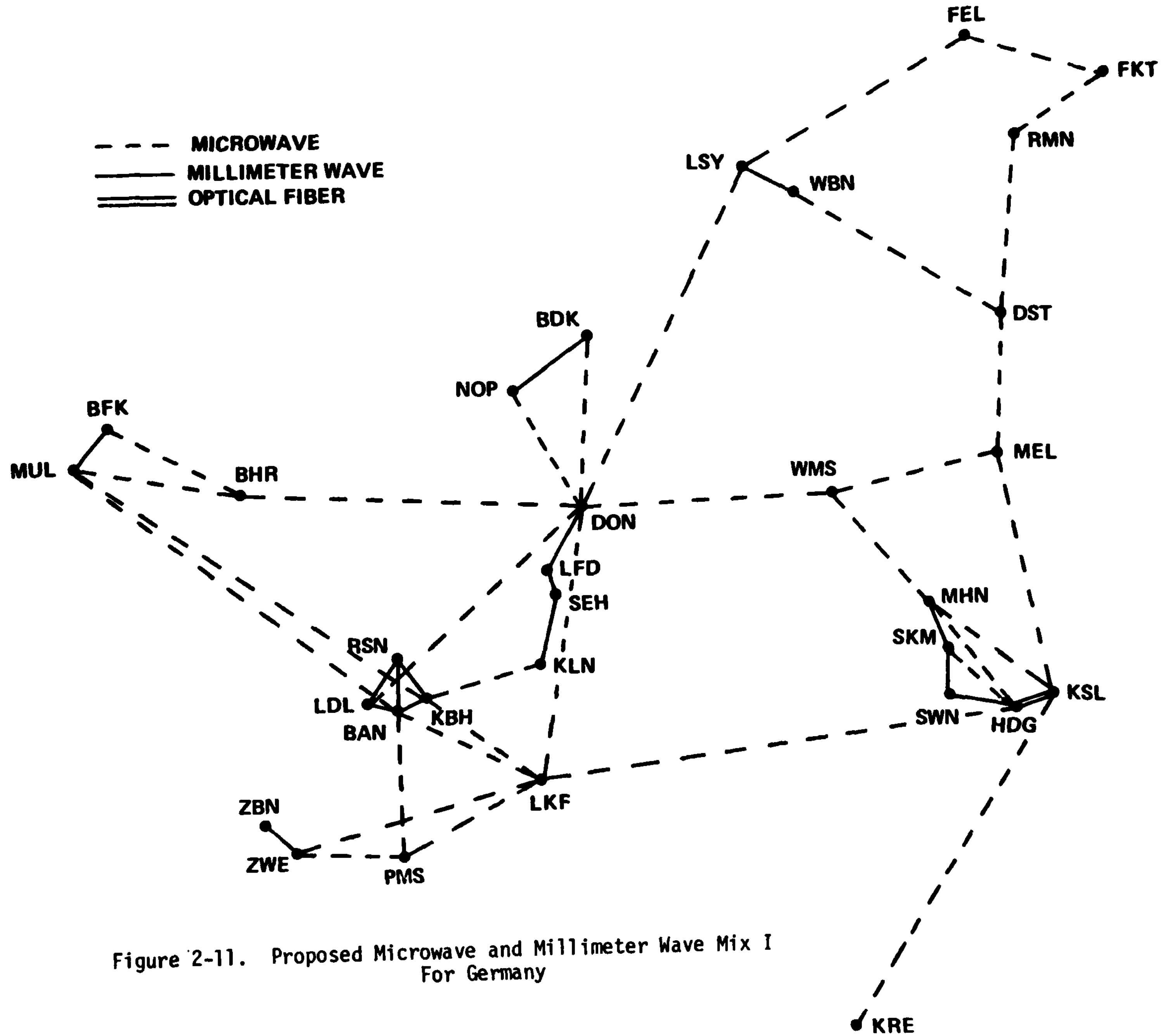

Figure 2-11. Proposed Microwave and Millimeter Wave Mix I For Germany

Table 2-16. Proposed Microwave and Millimeter Wave Mix I**

No.	Link	Channel*	No.	Link	Channel*
3	BAN-LKF	9/2 + 10	27	KLN-LKF	Delete
13	DON-LFD	13/3 + 20	28	KLN-SEH	21/4.5+20
21	HDG-KSL	5.5/1.5	32	LFD-SEH	14/3 + 20
23	HDG-SKM	15/3 + 10	36	MHN-SKM	15/3 + 10
40	BDK-NOP	0/2	44	LSY-WBN	0/2
41	DON-LKF	8.5/2	45	KSL-MHN	5.5/1.5
42	HDG-MHN	0/6 + 10	46	PMS-ZWE	0.5 /0
43	LKF-MUL	0/4			

*See note of Table 2-7

**See note of Table 2-8

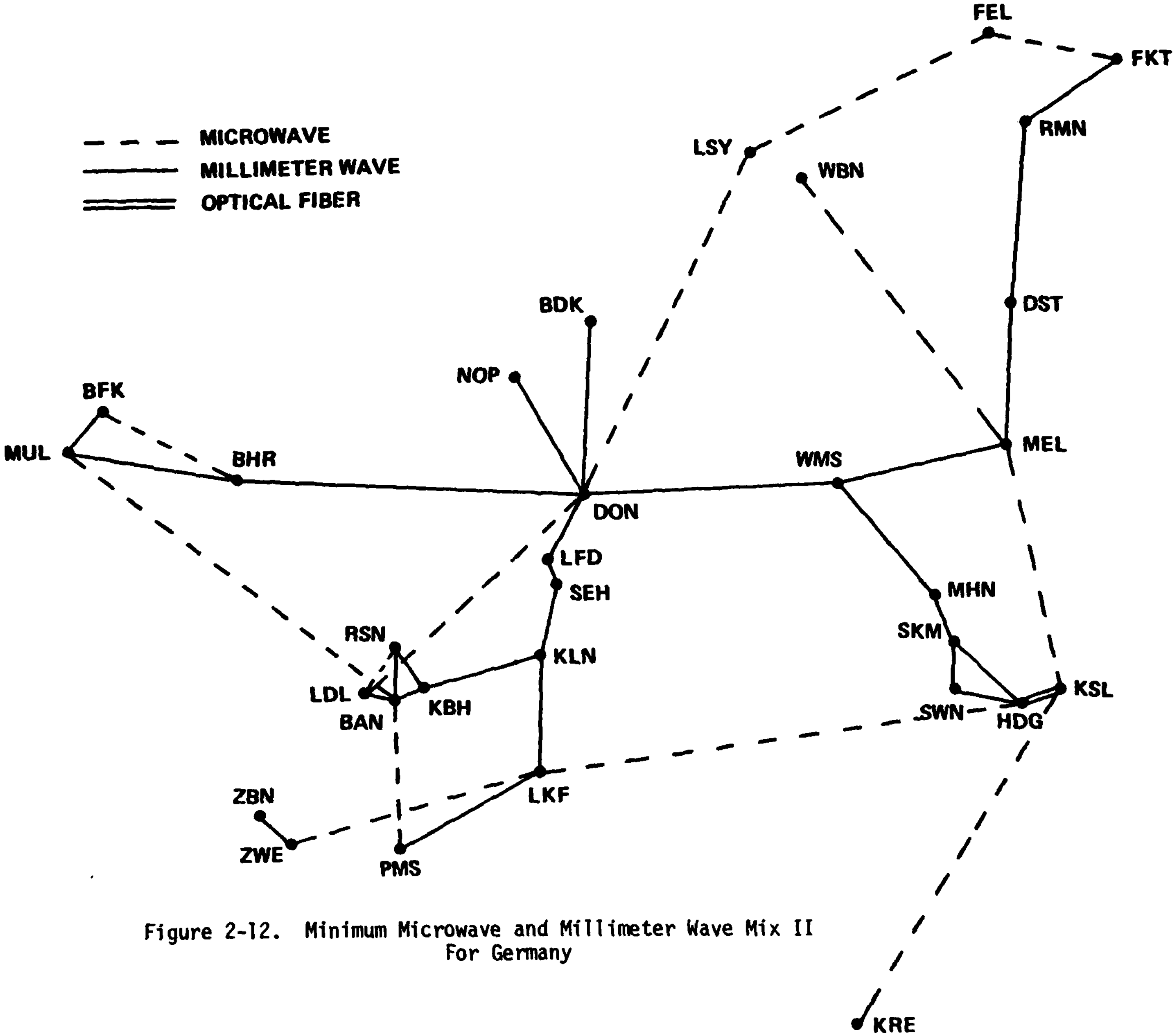

Figure 2-12. Minimum Microwave and Millimeter Wave Mix II
For Germany

Table 2-17. Minimum Microwave and Millimeter Wave Mix II

No.	Link	Channel*	No.	Link	Channel*
1	BAN-KBH	14/3 + 20	20	HDG-LKF	0/2 + 10
2	BAN-LDL	5.5/1.5 + 30	21	HDG-SKM	20.5/4.5 + 10
3	BAN-MUL	21.5/4.5 + 10	22	HDG-SWN	12.5/2.5 + 10
4	BAN-PMS	13/3	23	KBH-KLN	22/4.5 + 20
5	BAN-RSN	12.5/2.5 + 10	24	KBH-RSN	5/1
6	BDK-DON	2.5/.5	25	KLN-LKF	17.5/4 + 10
7	BFK-BHR	0/0 + 10	26	KLN-SEH	29.5/7 + 20
8	BFK-MUL	5.5/1.5 + 10	27	KRE-KSL	3/1
9	BHR-DON	9/2 + 10	28	KSL-MEL	5.5/1.5
10	BHR-MUL	7.5/1.5	29	LDL-RSN	6.5/1.5 + 10
11	DON-LDL	13/3 + 20	30	LFD-SEH	22.5/5.5 + 20
12	DON-LFD	21.5/5 + 20	31	LKF-PMS	11/2.5
13	DON-LSY	2.5/.5 + 10	32	LKF-ZWE	5/1
14	DON-NOP	1.5/.5	33	MEL-WBN	1.5/.5
15	DON-WMS	14/3 + 10	34	MEL-WMS	0.4 + 10
16	DST-FKT	0/2 + 10	35	MHN-SKM	20.5/4.5 + 10
17	DST-MEL	2.5/.5 + 10	36	MHN-WMS	14.5/3 + 10
18	FKT-LSY	0/2 + 10	37	SKM-SWN	5/1 + 10
19	HDG-KSL	11/2.5	38	ZBN-ZWE	4/1

*See note of Table 2-7

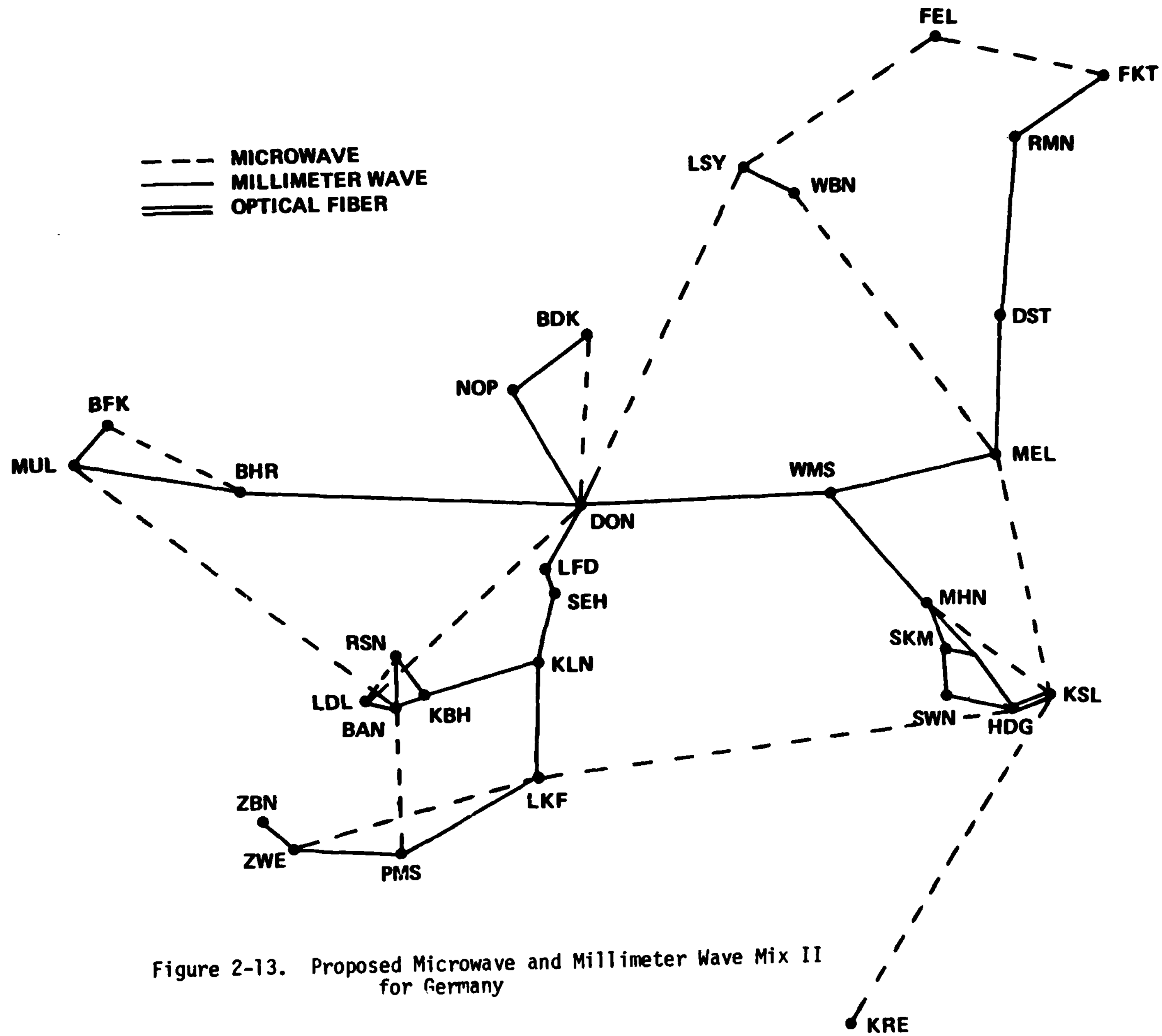

Figure 2-13. Proposed Microwave and Millimeter Wave Mix II for Germany

Table 2-18. Proposed Microwave and Millimeter Wave Mix II**

No.	Link	Channel*	No.	Link	Channel *
19	HDG-KSL	5.5/1.5	35	MHN-SKM	15/3
21	HDG-SKM	15/3 + 10			
39	BDK-NOP	0/2	42	LSY-WBN	0/2
40	HDG-MHN	0/6 + 10	43	PMS-ZWE	0/5
41	KSL-MHN	5.5/1.5			

* See note of Table 2-7

** See note of Table 2-8

3.0 ALTERNATIVE SYSTEM PERFORMANCE RE-EVALUATION

This section presents the results of re-evaluation of the proposed transmission alternatives as described in Phase II Task 1 Report . The re-evaluation alternative systems for Oahu Island, Hawaii are microwave LOS system, millimeter wave LOS system, and fiber optic system. For Central Germany, re-evaluated alternative systems are microwave LOS system, millimeter wave LOS system, microwave and millimeter wave mix I and mix II. The Hawaii leased commerical common carrier and Germany cost sharing fiber optic system are not subjected to re-evaluation because only qualitative system description not quantitive system design were accomplished in Task 1 due to availability of needed data.

The link performance re-evaluation has been done on a node-to-node basis, therefore, it does not deal with the network. The re-evaluation valided system parameters, such as transmit power, antenna size and gain, etc. to make sure that the system margin is provided for the required time availability.

3.1 INTRODUCTION

Section 3.1.2 of the Phase II Task 1 Report discussed the performance objectives. Link performance re-evaluations are required for three end-to-end (ETE) availability, 0.99, 0.95 and 0.90. In the 0.99 ETE availability case, link capacity reductions of 0, 10, 20, 30, and 50 percent are required for the link performance evaluation. Link capacity reduction may affect the following factors in a communication system design;

1. Can save RF power depending upon the link capacity reduction rate. For example, 50 percent link capacity reduction results in 3 dB transmitter power saving.
2. May reduce the number of RF radios if more than one set of radios are used for a link to support full capacity.
3. Can reduce the number of multiplexers and switching devices.

Of these factors, the third one is beyond the scope of this work (Ref. 1-3). For the first one, power saving is not significant in the performance evaluation or cost saving because 10 to 50 percent capacity reduction

can only save link power requirement from 0.5 to 3 dB. As shown in the link budget analysis, each link usually is provided with a system margin of 5 to 10 dB so that a 0.5 to 3 dB power saving due to the capacity reduction would not affect the link design. As for the second one, the three transmission media considered are wideband ones; no link requires two sets of radios for parallel operation. Thus, it is concluded that the capacity reduction is not a significant parameter and will not be considered in the performance evaluation.

In order to propose a degraded single node to node (NTN) availability allocation, the following is assumed:

- Outages due to satellite and terrestrial segment are proportionally degraded
- Outage due to equipment maintains the same value as the ETE 0.99 case, and only propagation outage contributes to performance degradation.

NTN availability allocations for each different transmission media will be discussed in the following subsections.

3.1.1 Microwave LOS System

From Page 3-8 of Phase II Task 1 Final Report, the outage due to propagation for a single NTN link can be found as follows:

1. ETE 0.90 case
   - Unavailability allocation to a 965 km voice reference channel; 1×10^{-2}
   - Outage due to propagation;
     $1 \times 10^{-2} - 8 \times 10^{-4}$ (equipment failure rate) $= 9.2 \times 10^{-3}$
   - Outage due to propagation for 14 LOS;
     $9.2 \times 10^{-3} \div 2 = 4.6 \times 10^{-3}$
   - Single 48 km LOS outage due to propagation
     $4.6 \times 10^{-3} \div 14 = 3.3 \times 10^{-4}$

The unavailability allocation, including equipment failure for a 48 km LOS system is 3.3×10^{-4} (Availability 0.99967).

2. ETE 0.95 case

- Unavailability allocation to a 965 km voice reference channel; 5×10^{-3}
- Outage due to propagation; $5 \times 10^{-3} - 8 \times 10^{-4} = 4.2 \times 10^{-3}$
- Outage due to propagation for 14 LOS: $4.2 \times 10^{-3} \div 2 = 2.1 \times 10^{-3}$
- Single 48 km LOS outage due to propagation; $2.1 \times 10^{-3} \div 14 = 1.5 \times 10^{-4}$

The unavailability allocation; including equipment failure rate, to the 48 km LOS is 1.8×10^{-4} (Availability 0.99982).

3. ETE 0.99 case

- Single 48 km LOS outage due to propagation; 7×10^{-6}

The unavailability allocation, including equipment failure rate to the 48 km LOS is 4×10^{-5} (Availability 0.99996).

The microwave link performance evaluation methodology has been discussed in the Phase IB Report (Ref. 1-2) and Section 5.1 of Phase II Task 1 Report (Ref. 1-3). The method of obtaining a fade margin in the Task 1 Report is a simplified version of that of the Phase IB Report. The method of the Phase IB Report is mainly based on the DCEC Reports (Ref. 3-1 and 3-2). The DCEC EP 27-77 report also presents the relationship between fade margin and microwave link path length. Those two DCEC reports derived the fade margin requirement from the probability of fade outage that falls in the range III, which means that outages with durations greater than five seconds but less than one minute (Ref. 3-3). It will be shown that the fade margins obtained from two different methods are not much different.

Antenna size and RF transmitter power are assumed from the practical point of view that transmitter power is fixed. Antenna size will be varied according to path length variation. Antenna size and gain relationships are listed in Table 3-1.

Table 3-1. Parabolic Antenna Gain for 8 GHz

Antenna Diameter m (ft)	Antenna Gain dB_i
1.22 (4)	37.3
1.83 (6)	40.8
2.44 (8)	43.3
3.05 (10)	45.3
3.66 (12)	46.8
4.57 (15)	48.8

3.1.2 Millimeter Wave LOS System

As specified in Section 3.3.2.2 of the Phase II Task 1 Report, there is, as yet, no standard availability allocation for a millimeter wave radio link. Since a millimeter wave radio handles smaller power than a microwave radio, it was tentatively suggested for unavailibility due to equipment failure to have half that of microwave, that is, 1.8×10^{-5} A millimeter wave LOS link should have more unavailability allocation due to propagation than a microwave LOS because of rainfall attenuation. Tentatively, 3.5×10^{-5} is allocated to 10 km millimeter wave LOS link propagation outage. Those numbers are assumed to be based on 0.99 ETE availability requirement. Availability allocations stated in the (Ref. 3-3) are based on three transmission media; satellite, microwave LOS, and troposcatter. Hence, availability allocation must be adjusted for each transmission medium if millimeter wave LOS links are proposed as one of terrestrial segments and the 0.99 ETE availability

requirement is to be met. As a final comment on millimeter wave LOS link performance evaluation, it is noted that outage due to rainfall dominates multipath fading and they do not occur simultaneously. The following unavailability (availability) allocations are for 10 km path length millimeter wave LOS links.

1. ETE 0.90 case

   - Unavailability due to equipment failure; 1.8×10^{-5}

   - Unavailability due to propagation; 5.12×10^{-4}

   The unavailability allocation, including equipment failure, to the 10 km millimeter wave LOS is 5.3×10^{-4} (Availability 0.99947).

2. ETE 0.95 case

   - Unavailability due to equipment failure; 1.8×10^{-5}

   - Unavailability due to propagation; 8.8×10^{-5}

   The unavailability allocation, including equipment failure, to the 10 km millimeter wave LOS is 1.06×10^{-4} (Availability 0.9999)

3. ETE 0.99 case

   - Unavailability due to equipment failure; 1.8×10^{-5}

   - Unavailability due to propagation; 3.5×10^{-5}

   The unavailability allocation, including equipment failure, to the 10 km millimeter wave LOS is 5.3×10^{-5} (Availability 0.999947).

A millimeter wave radio has been proposed to use 36 GHz. The higher frequency antenna has such a narrow beamwidth that it is difficult to use a large high gain antenna because of antenna alignment. Thus, reducing repeater spacing may be better than increasing antenna gain. However,

there is also limitation because reducing repeater spacing requires a larger number of repeaters (RF equipment) and that fact induces bigger unavailability allocation due to equipment failure.

3.1.3 Optical Fiber Link

The optical fiber telecommunications link is an area of rapidly developing technology. Since optical fiber link is not significantly influenced by atmospheric conditions and its losses (including connector and splicing) are being reduced rapidly, malfunction and monitoring capability and number of redundant cables, as well as switching devices are believed to have a relationship to availability requirements. These components are either being developed or field tested, therefore, no data is available for their reliability, maintenance, expected life, etc.

As an overall suggestion of availability allocations for the future, the following are proposed to meet ETE 0.99 availability requirements:

- Increase availability allocation for optical fiber links
- Allocate smaller availability for millimeter wave link than microwave links
- Reduce equipment failure allocation, as developing device technology is rapidly improving.

3.2 HAWAII ALTERNATIVE TRANSMISSION SYSTEM

Three transmission alternatives, microwave LOS system, millimeter wave LOS system, and fiber optic system are evaluated for three specified ETE availabilities. Since Oahu Island is small all LOS links are short in path length. Links of microwave LOS system do not have any difficulty in satisfying the required time availability. Hawaii is one of the areas of the world with a large amount of rainfall, thus, required ETE availability limits the allowable repeater spacing of a millimeter wave LOS system.

3.2.1 Microwave LOS System

Three different end-to-end (ETE) availabilities 0.99, 0.95 and 0.90 are imposed upon the proposed microwave LOS systems in Hawaii. The proposed system parameters will be re-evaluated in Section 3.2.1.1, 3.2.1.2 and 3.2.1.3 in order to meet the three different availability requirements.

3.2.1.1 0.99 ETE

The unavailability allocation to the 48 km LOS is calculated to be 4×10^{-5}, where 7×10^{-6} is due to propagation outage and 33×10^{-6} is due to equipment failure. The unavailability allocation to shorter path length is proportionally reduced with respect to the 48 km LOS.

In Hawaii, there are a total twenty-one LOS links, the longest link is 18.0 km, and the shortest link is 1.8 km. Three different path lengths 18 km, 10km and 5 km will be used for discussion and comparison. The microwave LOS methodology developed in Phase II Task 1 Report and in Section 3.1 will be applied here.

The propagation outage in microwave LOS is mainly due to multipath fading. Therefore, the propagation outage allocation will be used equivalently as the probability of fading outage in our discussions. In Phase II Task 1 Report, equations (5-5), (5-6) and (5-7) will be applied to compute propagation outage with/without diversity techniques.

Space diversity is employed to reduce the effect of multipath fadings and thus improve link availability. With the stringent availability requirement, space diversity is a sound technique in the proposed system.

A summary of propagation outage for 5 km, 10 km and 18 km is shown in Table 3-2. The following parameters are assumed in the calculation.

- RF Frequency 8 GHz
- Average terrain with some roughness under the RF path; thus the constant "a" = 1 is used in equation (5-6)
- Humid and hot area is assumed in Hawaii; thus the constant "b" = 1/2 is used in equation (5-6)
- 10 meters vertical space diversity is employed.

Table 3-2. Rainfall Attenuation and Propagation Outage for 0.99 ETE Availability

Path Length (km)	5	10	18
Fade Margin (dB)	32	32	32
Improvement Factor (Equation 5-7)	253	127	70.4
Non-Diversity Fade Outage Probability (Equation 5-6)	3.2×10^{-6}	25×10^{-6}	147×10^{-6}
Probability of Fade Outage with Diversity (Equation 5-5)	0.03×10^{-6}	0.20×10^{-6}	20.9×10^{-6}
Propagation Outage Allocation	0.73×10^{-6}	1.45×10^{-6}	2.63×10^{-6}

From Table 3-2, it is easily seen that the system can meet the probability outage allocation only with space diversity techniques.

A link budget analysis is shown in Table 3-3. In the analysis, RF equipment is the same for the three cases, path length, space loss, antenna gain (antenna size) are different. The system margins for 18 km, 10 km, and 5 km are 10.9 dB, 16.0 dB and 22.1 dB, respectively.

3.2.1.2 0.95 ETE

The unavilability allocation to the 48 km LOS is 1.8×10^{-4}, where 1.5×10^{-4} is due to propagation outage and 0.3×10^{-4} is due to equipment failure.

A large portion of unavailability is allocated to propagation outage; the equipment failure allocation is the same as that of 0.99 ETE. A summary of propagation outage for three different path lengths, 18 km, 10 km, and 5 km, is shown in Table 3-4. The same assumptions as Table 3-2 are applied here except no diversity technique is used.

Table 3-3. Microwave LOS Link Analysis for 0.99 ETE Availability

PARAMETER	VALUE		
Path Length (km)	18	10	5
Frequency (GHz)	8	8	8
Bandwidth (MHz)	14	14	14
Data Rate (Mbps) (Bandwidth Efficiency 4 bit/sec/Hz)	52	52	52
RF Transmitter Power (dBW)	3	3	3
Losses Associated with Transmitter Station (dB)	37.3 (4 ft.)	37.3 (4 ft.)	37.3 (4 ft.)
Space Loss (dB)	135.7	130.6	124.5
Loss due to all other transmission loss (scintillation, reflection, etc.) (dB)	3	3	3
Fade Margin (dB)	32	32	32
Receiver Antenna Gain (dB)	37.3 (4 ft.)	37.3 (4 ft.)	37.3 (4 ft.)
Losses Associated with Receiver Station (dB)	3	3	3
Receiver Noise Figure (dB)	5	5	5
Receiver Noise (dBW)	-133	-133	-133
SNR @ 10^{-4} BER (16 Level QAM) (dB)	18	18	18
System Margin (dB)	10.9	16.2	22.1

Table 3-4. Rainfall Attenuation and Propagation Outage for 0.95 ETE Availability

Path Length (km)	5	10	18
Fade Margin (dB)	37	37	37
Non-Diversity Fade Outage Probability (Equation 5-6)	0.010×10^{-4}	0.08×10^{-4}	0.46×10^{-4}
Propagation Outage Allocation	0.16×10^{-4}	0.31×10^{-4}	0.56×10^{-4}

From Table 3-4, the non-diversity fade outage probability with 37 dB fade margin is less than the propagation outage allocation. Therefore, diversity technique is not needed.

The link budget analysis for 18 km, 10 km, and 5 km are the same as Table 3-3, except the fade margins are increased from 32 dB to 37 dB, thus the system margins are reduced to 5.9 dB, 11 dB, and 17.1 dB for 18 km, 10 km, and 5 km, respectively. Therefore, the system proposed for 0.95 ETE is the same as that for 0.99 ETE, except no space diversity technique is used.

3.2.1.3 <u>0.90 ETE</u>

The unavailability allocation to the 48 km LOS is 3.6×10^{-4}, where 3.3×10^{-4} is due to propagation outage and 0.3×10^{-4} is due to equipment failure. Relatively higher propagation outage is allocated. Therefore, the system can maintain the required availability without the diversity technique. A summary of propagation outage for 18 km, 10 km, and 5 km path length is shown in Table 3-5. The assumptions made for Table 3-2 are applicable here except no diversity is employed.

Table 3-5. Rainfall Attenuation and Propagation Outage for 0.90 ETE Availability

Path Length (km)	5	10	18
Fade Margin (dB)	35	35	35
Non-Diversity Fade Outage Probability (Equation 5-6)	0.02×10^{-4}	0.13×10^{-4}	0.74×10^{-4}
Propagation Outage Allocation	0.34×10^{-4}	0.69×10^{-4}	1.24×10^{-4}

The link budget analysis in Table 3-3 is still applicable. The only differences are the fade margin is increased from 32 dB to 35 dB, thus the system margins become 7.9 dB, 20.0 dB, and 19.1 dB for 18 km, 10 km, and 5 km, respectively.

It is noted that the ratio of propagation outage allocation for ETE 0.99, ETE 0.95 and ETE 0.90 is 0.07:1.5:3.3. The difference between ETE 0.95 and ETE 0.90 is quite minimal. Therefore, the system parameters could be almost interchangeable between ETE 0.95 and 0.90 systems. It is concluded that the same RF equipment is proposed for ETE 0.99, 0.95 and 0.90 systems. Space diversity is applied only to ETE 0.99 system.

3.2.2 Millimeter Wave LOS System

The millimeter wave LOS system performance re-evaluations for ETE 0.90, 0.95, and 0.99 are presented in this section. The three different ETE availability requirements are discussed separately in Sections 3.2.2.1, 3.2.2.2 and 3.2.2.3.

3.2.2.1 0.90 ETE

The unavailability allocation to a 10 km millimeter wave LOS is 5.3×10^{-4}, where 5.12×10^{-4} is due to propagation outage, and 1.8×10^{-5} is due to equipment failure. For a shorter path length, the unavailability allocation is proportionally reduced according to the ratio of the path length and 10 km.

Rain attenuation is the major factor which contributes to the propagation outage. Therefore, the percentage of time that the rain attenuation exceeds the allocated margin is equivalent to the propagation outage. For detailed discussion on rain attenuation, refer to Section 5.2.1 of Phase II Task 1 Final Report.

In Hawaii, a total of 29 links are proposed, the longest path length is 8.1 km, the shortest is 1.8 km. Table 3.2-5 shows the rain attenuation and propagation outage for 8.1 km, 5.0 km, and 3.0 km, path lengths. These three path lengths are chosen as reference for discussion and comparison. The rain attenuation can be easily calculated by the method developed in Section 5.2.1 of Phase II Task 1 Final Report. The following assumptions are made to construct Table 3-6.

- RF frequency 36 GHz
- Rain zone 2 is used to characterize the rain climate in Hawaii
- The rainfall is evenly distributed over the path

Table 3-6. Rainfall Attenuation and Propagation Outage
for 0.90 ETE Availability

Path Length (km)	8.1	5.0	3.0
Rain Attenuation (dB/km)	6.5	8.5	10.0
Total Rain Attenuation (dB)	52.7	42.5	30.0
Propagation Outage	4.15×10^{-4}	2.56×10^{-4}	1.54×10^{-4}

A link budget analysis for 8.1 km, 5.0 km, and 3.0 km path lengths is shown in Table 3-7. The system margins are 15.4 dB, 29.7 dB, and 36.6 dB for 8.1 km, 5.0 km, and 3.0 km. Therefore, the proposed system can easily meet ETE 0.90.

The total number of repeaters proposed are eleven as indicated in Phase II Task 1 Final Report.

Table 3-7. Millimeter Wave LOS Link Analysis for 0.90 ETE Availability

PARAMETER	VALUE		
Path Length (km)	8.1	5.0	3.0
Frequency (GHz)	36	36	36
Bandwidth (MHz)	17.3	17.3	17.3
Data Rate (Mbps) (Bandwidth Efficiency 3 bps/Hz)	52	52	52
RF Transmitter Power (dBW)	3	3	3
Transmitter Antenna Gain (1m diameter) (dB)	49	49	49
Losses Associated with Transmitter (dB)	1.0	1.0	1.0
Space Loss (dB)	141.7	137.6	133.2
Loss due to Rain Attenuation (dB)	52.7	42.5	30.0
Loss due to all other Transmission Loss (Scintillation, reflection, oxygen and water vapor) (dB)	3.0	3.0	3.0
Receiver Antenna Gain (1m diameter) (dB)	49	49	49
Losses Associated with Receiver (dB)	1.0	1.0	1.0
Receiver Noise Figure (dB)	5.0	5.0	5.0
Receiver Noise Power (dBW)	-131.5	-131.5	-131.5
SNR @ 10^{-4} BER (8-PSK) (dB)	12.7	12.7	12.7
System Margin	15.4	29.7	36.6

3.2.2.2 0.95 ETE

The unavailability allocation to a 10 km millimeter wave LOS is 1.06×10^{-4}, where 8.8×10^{-5} is due to propagation outage and 1.8×10^{-5} is due to equipment failure.

Table 3-8 shows the rain attenuation and propagation outage for 5.0 km, 3.5 km, and 3.0 km path lengths. The same assumptions as Table 3.2-5 are applicable to construct Table 3.2-7.

Table 3-8. Rainfall Attenuation and Propagation Outage for 0.95 ETE Availability

Path Length (km)	5.0	3.5	3.0
Rain Attenuation (dB/km)	17.0	19.5	21.0
Total Rain Attenuation (dB)	85.0	68.2	63.0
Propagation Outage	4.4×10^{-5}	3.08×10^{-5}	2.64×10^{-5}

A link budget analysis for 5.0 km, 3.5 km, and 3.0 km with the same types of RF equipment as ETE 0.90 are shown in Table 3.2-8. In order to have a minimum system margin, 3.5 km path length seems to be the maximum path length allowed for ETE 0.95. Therefore, repeater(s) should be inserted in those path lengths longer than 3.5 km in the proposed system. By a rough calculation, a total of 32 repeaters are needed.

3.2.2.3 0.99 ETE

The unavailability allocation to the 10 km millimeter wave LOS is 5.3×10^{-5}, where 3.5×10^{-5} is due to propagation outage, and 1.8×10^{-5} is due to equipment failure. The same equipment failure allocation is applied for ETE 0.99, 0.95 and 0.90, thus the same RF equipment is assumed. The 0.99 ETE is the most stringent requirement, a shorter path length is expected in the design.

The rain attenuations for 3.0 km, 2.5 km, and 2.0 km are tabulated in Table 3-9.

Table 3-9. Millimeter Wave LOS Link Analysis for 0.95 ETE Availability

PARAMETER	VALUE		
Path Length (km)	5.0	3.5	3.0
Frequency (GHz)	36	36	36
Bandwidth (MHz)	17.3	17.3	17.3
Data Rate (Mbps) (Bandwidth Efficiency 3 bps/Hz)	52	52	52
RF Transmitter Power (dBW)	3	3	3
Transmitter Antenna Gain (1m diameter) (dB)	49	49	49
Losses Associated with Transmitter (dB)	1.0	1.0	1.0
Space Loss (dB)	137.6	+135.7	133.2
Loss due to Rain Attenuation (dB)	85	68.2	63
Loss due to all other Transmission Loss (Scintillation, reflection, oxygen and water vapor) (dB)	3.0	3.0	3.0
Receiver Antenna Gain (1m diameter) (dB)	49	49	49
Losses Associated with Receiver (dB)	1.0	1.0	1.0
Receiver Noise Figure (dB)	5	5	5
Receiver Noise Power dBW)	-131.5	-131.5	-131.5
SNR @ 10^{-4} BER (8-PSK) (dB)	12.7	12.7	12.7
System Margin (dB)	-12.8	5.9	13.6

Table 3-10. Rainfall Attenuation and Propagation Outage for 0.99 ETE Availability

Path Length (km)	3.0	2.5	2.0
Rain Attenuation (dB/km)	27.0	28.0	29.0
Total Rain Attenuation (dB)	81.0	70.0	58.0
Propagation Outage	1.05×10^{-5}	0.88×10^{-5}	0.7×10^{-5}

A link budget analysis for 3.0 km, 2.5 km, and 2.0 km is shown in Table 3-11. The system margins are -4.4 dB, 8.2 dB, and 22.2 dB for 3.0 km, 2.5 km, and 2.0 km. A 2.5 km path length with 8.2 dB system margin seems to be the maximum distance allowed in the system design. The total number of repeaters required is approximately 49 by a rough calculation.

We conclude that the same RF equipment is proposed for different ETE availability. The path length constraints are 8.1 km, 3.5 km, and 2.5 km for ETE 0.90, 0.95 and 0.99, respectively. The total number of repeaters proposed are 11, 32 and 49 for ETE 0.90, 0.95 and 0.99, respectively.

3.2.3 Fiber Optical System

Since optical fiber is a cable link not experiencing atmospheric effects, such as rain attenuation, scintillation fading, etc.,any outages are long-term. The BER threshold beyond which the cable link will be considered available is 1×10^{-7}.

The objective availability of optical fiber is 0.99995 minimum per link or 0.99 end-to-end (Ref. 3-3). Availability is the cumulative percentage of time that the cable system is not in an outage condition where an outage is defined as a bit error rate in excess of 10^{-7} for a period in excess of one minute for the end-to-end cable system.

Table 3-11. Millimeter Wave LOS Link Analysis for 0.99 ETE Availability

PARAMETER	VALUE		
Path Length (km)	3.0	2.5	2.0
Frequency (GHz)	36	36	36
Bandwidth (MHz)	17.3	17.3	17.3
Data Rate (Mbps) (Bandwidth Efficiency 3 bps/Hz)	52	52	52
RF Transmitter Power (dBW)	3	3	3
Transmitter Antenna Gain (1m diameter) (dB)	49	49	49
Losses Associated with Transmitter (dB)	1.0	1.0	1.0
Space Loss (dB)	133.2	131.6	129.6
Loss due to Rain Attenuation (dB)	81	70	58
Loss due to all other Transmission Loss (Scintillation, reflection, oxygen and water vapor) (dB)	3.0	3.0	3.0
Receiver Antenna Gain (1m diameter) (dB)	49	49	49
Losses Associated with Receiver (dB)	1.0	1.0	1.0
Receiver Noise Figure (dB)	5	5	5
Receiver Noise Power (dBW)	-131.5	-131.5	-131.5
SNR @ 10^{-4} BER (8-PSK) (dB)	12.7	12.7	12.7
System Margin (dB)	-4.4	8.2	22.2

There is no standard way to compute the objective availability of an optical fiber link ETE 0.95 and ETE 0.90. By assuming the unavailability is proportional degraded with respect to ETE 0.99, the objective availabilities for ETE 0.95 and 0.90 are shown in Table 3-12.

Table 3-12. Availability Allocation for Fiber Optic System

ETE Availability	ETE Unavailability	Link Unavailability	Link Availability
0.99	0.01	5×10^{-5}	0.99995
0.95	0.05	25×10^{-5}	0.99975
0.90	0.10	50×10^{-5}	0.99950

The major contribution to total unavailability is expected to be cable damage and electronic failure. The propagation outage is minimum and will be neglected in the analysis.

The availability allocation to an optical fiber link is 0.99995. In Hawaii, there are a total of 23 links. The longest link is 29.4 km, the shortest is 1.0 km. As mentioned in Phase II Task 1 Final Report, repearterless transmission was proposed in the network design. An optical fiber link with length 30 km and data rate of 52 Mbps is used as a postulated link in the analysis.

A power budget analysis for the 30 km link is shown in Table 3-13. The system parameters are obtained from Phase II Task 1 Final Report. The total system margin is 17 dB. The margin will be higher for shorter links.

Table 3-13. Link Budget Analysis for the Proposed Fiber Optic System

PARAMETER	VALUE
Optical Wavelength (μm)	1.3
Path Length (km)	30
Data Rate (Mbps)	52
ILD Output (dBm)	0
Power Degradation at End of Life (dB)	2
Coupling loss (NA - 0.2) (dB)	3
Fiber Loss (0.5 dB/km) (dB)	15
Splicing Loss (0.5 dB each) 2 km/splicing (dB)	7.5
Connector Loss (0.5 dB each) (dB)	2.0
Detector Coupling Loss (dB)	0.5
Detector Temperature Degradation Loss (dB)	2
Received Power (dBm)	-32
Required Received Power (10^{-7} BER) (dBm)	-49
System Margin (dB)	17

The unavailability allocation for a 30 km link is 5×10^{-5} (or 0.438 hours per year). The major contribution to total unavailability is expected to be fiber damage and electronic failure. The time for repair is the largest potential source of outage time. Propagation outage is considered to be negligible.

Most fiber installations to date employed conventional telephone company techniques and equipment. As long as the fiber specifications regarding maximum allowable tension and minimum bend radius are observed, the cables can be treated just like coaxial cables. Most of cable damages are due to extrinsic failures, such as, improper installations, digups, breaking poles, collapsing ducts, etc. Because of similarity

between fiber cable and coaxial cable, the history of coaxial cable failure could be used as a reference for reliability study (Ref. 3-4).

It has been proven by reliability tests that mean time between failures (MTBF) of the LED transmitter can be estimated at more than 1.4×10^6 hours at present (Ref. 3-5). The LED transmitter includes the LED driver, LED itself and interfaces.

There is little reported work on detector reliability studies. Nevertheless, requirements on detector reliability are expected to be as equally stringent as LED (1.4×10^6 hours).

Table 3.2-13 shows the predicted service outage due to cable damage and electronic failure. The equation to compute service outage due to cable damage is expressed by

$$So = I \times (Tl - S) \times T$$

where So = Service outage in hr/year

I = Incidents per year

Tl = Average tube lost

S = Spare tubes, 2 spare tubes are assumed

T = Mean down time

From Table 3-14, the total service outage is 0.3830 (hr/year) or link availability is 0.999956.

The current installed fiber optic systems can easily meet the ETE 0.99 requirement. By the year 2000, the reliability of fiber and electronic equipment will be greatly improved without paying additional cost. For ETE 0.95 and 0.90, the fiber and equipment specifications could be relaxed. However, the cost saving is quite minimal.

3.3 CENTRAL GERMANY ALTERNATIVE TRANSMISSION SYSTEM

Four alternative transmission systems, microwave LOS system, millimeter wave LOS system, microwave and millimeter wave mix I and II

Table 3-14. Outage Allocation for 30km Fiber Optic System

FAILURE CAUSE	INCIDENTS PER YEAR	AVERAGE TUBE LOST	MEAN DOWN TIME (HR)	SERVICE OUTAGE (HR/YEAR)
Cable				
Telephone Co. Activity	0.0042	7	5.8	0.121
Foreign Workman	0.0113	5	6.7	0.227
Miscellaneous	0.0014	4	9.0	0.0252
Electronics				
Multiplexer	-	-	-	0.0020
Line Terminal Equipment	0.0031	-	2.0	0.0063
Miscellaneous	-	-	-	0.0015
Total Service Outage				0.3830

are re-evaluated for three different ETE availabilities. These results are presented in this section.

Unlike Hawaii alternative system, German networks consist of longer links. Consequently, long link such as 60 km has been examined for microwave system. As in the Hawaii case, re-evaluation of millimeter wave system focuses on the allowable repeater spacing to provide the specified ETE availability.

3.3.1 Microwave LOS System

The microwave LOS system for Germany has path length varying 2.3 km to 72.3 km and channel capacity 3T1 (4.6 Mbps) to 32 T1 ($\sim$ 52 Mbps including service channel). There are more than 40 link connections. Apparently, checking all links is not worthwhile because the required system gains differ by a few dB. Thus, the system parameters for the link will be found for three different lengths with a fixed bandwidth. The modulation scheme is an area of fast improving technology. With today's technology, more than 3.5 bits/s/Hz of bandwidth efficiency is feasible with 16-QAM modulation schemes. There is little doubt about achieving 4 bits/s/Hz of bandwidth efficiency in this decade. The currently required emission bandwidths for a microwave LOS digital radio set are 3.5, 7, 14, or 20 MHz (Ref. 3-3). With two assumptions that high bandwidth efficiency will be available and current emission bandwidth standard will be applied for the future, 14 MHz bandwidth is chosen for the system link budget analysis. Three different path lengths chosen for performance analysis are 20 km, 40 km, and 60 km. Other links which may have particular characteristics will be dealt with additional explanations.

3.3.1.1 0.90 ETE Availability

In the previous Section 3.1.1, the unavailability (availability) for a 48 km microwave LOS link has been specified. The unavailability allocation to a different path length can be obtained with linearly prorated conversion. The constants, a and b given in Eq. (5-6) of Phase II Task 1 Report are set to be 1 and 1/4, respectively.

<u>Case 1</u>: Link Distance 20 km

The minimum allowable propagation outage for a 20 km distance microwave LOS can be found from the given outage for a 48 km LOS by prorated conversion as follows:

$$\frac{20}{48} \times 3.3 \times 10^{-4} = 1.38 \times 10^{-4} \tag{3-1}$$

The non-diversity fading outage probability with a given 31 dB fade margin for a 20 km link distance can be obtained by using the Eq. (5-6).

$$\text{Undp} = \frac{1}{4} \times 10^{-5} \times 8 \times (20)^3 \times 10^{-3.1}$$

$$= 1.3 \times 10^{-4} \tag{3-2}$$

The number obtained in Eq. (3-2) is smaller than that of Eq. (3-1). Thus 31 dB fade margin is enough to meet the availability requirement.

The free space loss with 20 km path length and 8 GHz freqnecy is given by 136.6 dB. The receiver noise power with 14 MHz bandwidth is given by -133.4 dB. Then the required antenna gain for transmitter and receiver is 37.3 dB and its size is 1.22m (4 ft.). The link budget analysis is shown in Table 3-15. Note that the link budget has 11.4 dB of system margin. Therefore, without employing a diversity, the 20 km lingth LOS system will maintain a smaller unavailability than the required one, 1.38×10^{-4} which was diversity scheme but required hot-standby RF equipment to maintain the required equipment availability.

<u>Case 2</u>: Link Distance 40 km

The minimum alllowable propagation outage for a 40 km path length microwave LOS is given by

$$\frac{40}{48} \times 3.3 \times 10^{-4} = 2.75 \times 10^{-4} \tag{3-3}$$

Table 3-15. Microwave Los Link Analysis
For 0.90 ETE Availability

PARAMETER	VALUE		
Path Length (km)	20	40	60
Frequency (GHz)	8	8	8
Bandwidth (1) (MHz)	14	14	14
RF Transmit Power (2) (dBW)	3	3	3
Losses Associated with Transmitter (dB)	3	3	3
Transmitter Antenna Gain (dB)	37.3 (1.22 m dia.)	40.8 (1.88 m dia.)	43.3 (2.44 m dia.)
Free Space Loss (dB)	136.6	142.6	146.1
Losses due to all other Transmission Loss (Scintillation, reflection, etc.)	3	3	3
Fade Margin (dB)	31	37	41
Receiver Antenna Gain (dB)	37.3 (1.22 m dia.)	40.8 (1.88 m dia.)	43.3 (2.44 m dia.)
Losses Associated with Receiver (dB)	3	3	3
Receiver Noise Figure (dB)	5	5	5
Receiver Noise Power (dBW)	-133.4	-133.4	-133.4
Eb/No @ 10^{-4} BER (dB)	18	18	18
System Margin (dB)	11.4	6.4	3.9

1. Bandwidth efficiency is assumed to be either 4 bits/s/Hz (ex. 16-QAM) or 2 bits/sHz (ex. QPSK). That depends upon the bit rate requirement

2. Transmitter power can be reduced 500 mw (-3 dB) without reducing the system performance because the reduced transmit power is still able to provide 5.4 dB system margin. However, 2 watts power is proposed to be used as standard source power through the whole analysis including the most stringent requirement, i.e., 0.999 ETE case.

3. For bandwidth efficiency 4 bps/Hz, 18 dB is required, and for bandwidth efficiency 2 bps/Hz, 9 dB is required.

With 37 dB fade margin, the non-diversity fading outage probability is given by

$$\text{Undp} = \frac{1}{4} \times 10^{-5} \times 8 \times (40)^3 \times 10^{-3.7} = 2.55 \times 10^{-4} \qquad (3\text{-}4)$$

The link budget analysis is also shown in Table 3-15. This system does not employ a diversity scheme as Case 1.

<u>Case 3</u>: Link Distance 60 km

The minimum allowable propagation outage for a 60 km path length microwave LOS is given by

$$\frac{60}{48} \times 3.3 \times 10^{-4} = 4.13 \times 10^{-4} \qquad (3\text{-}5)$$

With 41 dB fade margin, the non-diversity fading outage probability is given by

$$\text{Undp} = \frac{1}{4} \times 10^{-5} \times 8 \times (60)^3 \times 10^{-4.1} = 3.4.3 \times 10^{-4} \qquad (3\text{-}6)$$

The link budget analysis is also shown in Table 3-15. The system does not employ any diversity scheme as the previous two cases. In conclusion, the following approaches have been adopted:

1. Use fixed RF transmit power, 2 Watts for any path length

2. Maintain the required availability without employing diversity scheme

3. Change antenna size according to path length variation.

4. Use hot-standby RF equipment for equipment failure.

3.3.1.2 0.95 ETE Availability

In the previous Section 3.1.1, availability for a 48 km microwave LOS is given by 0.99982, and outage due to propagation is allocated by 1.5×10^{-4} for 0.95 ETE availability requirement. Unlike the 0.90 ETE availability case, the systems need a diversity scheme to meet the availability requirement.

Case 1: Link Distance 20 km

The maximum allowable propagation outage for a 20 km distance microwave LOS is given by

$$\frac{20}{48} \times 1.5 \times 10^{-4} = 6.25 \times 10^{-5} \qquad (3\text{-}7)$$

The non-diversity fading outage probability with a given 28 dB fade margin for a 20 km link distance can be obtained from equation of Phase II Task 1 Report.

$$\text{Undp} = \frac{1}{4} \times 10^{-5} \times 8 \times (20)^3 \times 10^{-2.8} = 2.54 \times 10^{-4} \qquad (3\text{-}8)$$

The space diversity improvement with 5 m vertically separated antennas is found from Eq. (5-7) of the Phase II Task 1 Report (Ref. 1-3).

$$\text{Isd} = \frac{10^{-3} \times (5)^2 \times 8 \times 10^{2.7}}{20} = 6.3 \qquad (3\text{-}9)$$

The probability of fading outage with the space diversity is obtained by using Eq. (5-5) of the Phase II Task 1 Report (Ref. 1-3).

$$\text{Usd} = \frac{2.54 \times 10^{-4}}{6.3} = 4.0 \times 10^{-5} \qquad (3\text{-}10)$$

Case 2: Link Distance 40 km

The maximum allowable propagation outage for a 40 km path microwave LOS is given by

$$\frac{40}{48} \times 1.5 \times 10^{-4} = 1.25 \times 10^{-4} \qquad (3\text{-}11)$$

With 32 dB fade margin and 5 m antenna separation, Undp. Isd, and Usd are obtained as follows:

$$Ndp = \frac{1}{4} \times 10^{-5} \times 8 \times (40)^3 \times 10^{-3.2} = 8.1 \times 10^{-4} \qquad (3\text{-}12)$$

$$Isd = \frac{10^{-3} \times (5)^2 \times 8 \times 10^{3.2}}{40} = 7.9 \qquad (3\text{-}13)$$

$$Usd = \frac{8.1 \times 10^{-4}}{7.9} = 1.03 \times 10^{-4} \qquad (3\text{-}14)$$

Apparently, the number obtained in Eq. (3-14) satisfies the minimum allowable outage given in Eq. (3-8).

<u>Case 3</u>: Link Distance 60 km

The maximum allowable propagation outage for a 60 km distance microwave LOS is given by

$$\frac{60}{48} \times 1.5 \times 10^{-4} = 1.88 \times 10^{-4} \qquad (3\text{-}15)$$

With 35 dB fade margin and 5 m antenna separation, Undp, Isd, and Usd are obtained as follows:

$$Undp = \frac{1}{4} \times 10^{-5} \times 8 \times (60)^3 \times 10^{-3.5} = 1.37 \times 10^{-3} \qquad (3\text{-}16)$$

$$Isd = \frac{10^{-3} \times (5)^2 \times 8 \times 10^{3.5}}{60} = 10.5 \qquad (3\text{-}17)$$

$$Usd = \frac{1.37 \times 10^{-3}}{10.5} = 1.3 \times 10^{-4} \qquad (3\text{-}18)$$

The link budget analysis for three different path lengths is shown in Table 3-16.

In conclusion of Section 3.3.1.2, the following is noted:

1. These systems have at least a 9.9 dB system margin.
2. Use a space diversity scheme having 5 m antenna vertical separation
3. Use the fixed transmit power and change antenna size for path length variation
4. Compared to the previous case, 0.90 ETE availability, higher tower and greater cost will be needed because of space diversity.

Table 3-16. Microwave LOS Link Analysis
For 0.95 ETE Availability

PARAMETER	VALUE		
Path Length (km)	20	40	60
Frequency (GHz)	8	8	8
Bandwidth (MHz)	14	14	14
RF Transmit Power (dBW)	3	3	3
Losses Associated with Transmitter (dB)	3	3	3
Transmitter and Receiver			
Antenna Size (m)	1.22	1.83	2.44
Antenna Gain (dB)	3.73	40.8	43.3
Free Space Loss (dB)	136.6	142.6	146.1
Losses due to other Transmission Loss (Scintillation, reflection, etc.) (dB)	3	3	3
Fade Margin (dB)	28	32	35
Losses Associated with Receiver (dB)	3	3	3
Receiver Noise Figure (dB)	5	5	5
Receiver Noise Power (dBW)	-133.4	-133.4	-133.4
Eb/No @ 10^{-4} BER (dB	18	18	18
System Margin	14.4	11.4	9.9

3.3.1.3 0.99 ETE Availability

The 0.99 ETE availability, is the most stringent requirement, and can also be called standard time availability for common military communications systems under normal conditions. Section 3.1.1 stated that availability for a 48 km microwave LOS under 0.99 ETE availability is 0.99996 and outage due to propagation is 7×10^{-6}. There is no doubt that the diversity scheme should be employed to achieve the tighten fading outage requirement. Two DCEC technical reports illustrated the relationship between path length and required fade margin under 0.99 ETE availability requirements. (Ref. 3-1 and 3-2).

Link 0.95 ETE availability case system also needs space diversity to meet the most stringent availability requirement. 10 m vertically separated antennas are suggested. The DCEC (Ref. 3-1) reports showed the relationship with 9.1 m antenna separated space diversity.

The maximum allowable propagation outages for three different path lengths are given:

$$\frac{20}{48} \times 7 \times 10^{-6} = 2.9 \times 10^{-6} \text{ for 20 km}$$
$$= 5.8 \times 10^{-6} \text{ for 40 km}$$
$$= 8.8 \times 10^{-6} \text{ for 60 km} \qquad (3\text{-}19)$$

With 31 dB, 36 dB, and 38 dB fade margin, Undp, Isd, and Usd for three different path lengths are given as follows, respectively.

$$\text{Undp} = \frac{1}{4} \times 10^{-5} \times 8 \times (20)^3 \times 10^{-3.1} = 1.27 \times 10^{-4}$$
$$\text{Isd} = 10^{-3} \times \frac{(10)^2 \times 8 \times 10^{3.1}}{20} = 50.4$$
$$\text{Usd} = \frac{1.27 \times 10^{-4}}{50.4} = 2.5 \times 10^{-6} \qquad \text{for 20 km}$$

$$\text{Undp} = 3.2 \times 10^{-4}$$
$$\text{Isd} = 80$$
$$\text{Usd} = 4 \times 10^{-6} \qquad \text{for 40 km}$$

$$\text{Undp} = 6.8 \times 10^{-3.8}$$
$$\text{Isd} = 84$$
$$\text{Usd} = 8 \times 10^{-6} \qquad \text{for 60 km} \; (3\text{-}20)$$

The DCEC report (Ref. 3-1) shows the required fade margin for the three different path lengths with average terrain and climatic conditions which can apply for the Germany case as follows: 28 dB for 20 km, 34 dB for 40 km, and 38 dB for 60 km. There are differences between the DCEC report and the Task 1 Report: 3 dB for 20 km, 2 dB for 40 km. But the values of DCEC report have been based on the probability of fade outage greater than five seconds. The reason why this probability of fade outage is chosen and the method of evaluating its value have been explained in the Phase IB Report (Ref. 1-2) of this work. The DCEC Report (Ref. 3-1) shows another link margin "design objective" where the fade margin requirements for longer links are relaxed because of the expense to achieve a better outage figure. But, the most stringent values, which came from the Phase II Task 1 Report have been chosen as the required fade margin. The link budget analysis for three different lengths is shown in Table 3-17.

3.3.3 Millimeter Wave LOS System

The millimeter LOS system for Germany has more than 40 links and path lengths varying from 2.3 km to 51.4 km. Since there is no standard emission bandwidth for millimeter waves, 17.3 MHz bandwidth and 3 bps/Hz bandwidth efficiency (ex. 8-PSK) are tentatively proposed as a candidate. The number of repeaters for each link mainly depends upon the path length and rainfall attenuation. It is obvious that the repeater spacing cannot exceed more than 10 km because of heavy rainfall attenuation characteristics of millimeter waves. There is a contradiction for the repeater spacing: the shorter the repeater spacing proposed to combat rainfall attenuation, the more numbers of repeaters are used and more outage due to equipment failure.

Unlike the approach used in microwave in which link distances were fixed and system parameters were changed to meet the availability requirements, this section will investigate how long repeater spacing is allowable with fixed system parameters under the required ETE availability.

3.3.2.1 0.90 ETE Availability

In the previous Section 3.1.2, the unavailability for a 10 km millimeter wave LOS link has been specified as 5.3 x 10-4, where 5.12×10^{-4}

Table 3-17. Microwave LOS Link Analysis
For 0.99 ETE Availability

PARAMETER	VALUE		
Path Length (km)	20	40	60
Frequency (GHz)	8	8	8
Bandwidth (MHz)	14	14	14
RF Transmit Power (dBW)	3	3	3
Losses Associated with Transmitter (dB)	3	3	3
Transmitter and Receiver Antenna			
Size (m)	1.22	1.83	2.44
Gain (dB)	37.3	40.8	43.3
Free Space Loss (dB)	136.6	142.6	146.1
Losses due to Other Transmission Loss (Scintillation, reflection, etc.) (dB)	3	3	3
Fade Margin (dB)	31	36	38
Antenna Vertical Separation (m)	10	10	10
Losses Associated with Receiver (dB)	3	3	3
Receiver Noise Figure (dB)	5	5	5
Receiver Noise Power (dBW)	-133.4	-133.4	-133.4
Eb/No @ 10^{-4} BER (dB)	18	18	18
System Margin (dB)	11.4	6.4	6.9

is allocated to outage due to propagation, and 1.8×10^{-5} is allocated to equipment failure. Since the multipath fading and heavy rainfall attenuation do not occur simultaneously and rainfall attenuation dominates the multipath fading, the entire propagation outage 5.12×10^{-4} may be assigned to the rainfall attenuation. The rainfall attenuation characteristics in millimeter waves frequency band have been widely studied by many authors and institutes, but it is still not enough to apply them directly, as the results mainly lean to satellite applications and do not provide information as to how far, how long a time, and how often the heavy rainfall affects a specific region. Summarized information has been discussed in the Phase IB and Phase I Task 1 Report. (Ref. 1-2 and 1-3). Germany belongs to curve 3 in Figure 5-3 of Phase II Task 1 Report. (Ref. 1-3). The maximum allowable outage rates and their corresponding rain attenuations for three different path lengths are shown in Table 3-18.

Table 3-18. Rainfall Attenuation and Propagation Outage for 0.90 ETE Availability

Path Length (km)	5	10	15
Propagation Outage	2.56×10^{-4}	5.12×10^{-4}	7.68×10^{-4}
Rainfall Rate (mm/hr)	23	15	13
Rain Attenuation Rate (dB/km)	6.0	4.0	3.5
Total Rain Attenuation (dB)	30	40	52.5

The link budget analysis for three different path lengths is shown in Table 3-19.

As seen in the link budget analysis, the system margin for 15 km path length millimeter wave LOS link is larger than 4 dB excluding rainfall attenuation. Thus, it can be suggested that 15 km repeater spacing is economical for long links. For short links, antenna size and/or transmit power can be reduced without losing availability because the systems have more than enough system margins.

Table 3-19. Millimeter Wave LOS Link Analysis for 0.90 ETE Availability

PARAMETER	VALUE		
Path Length (km)	5	10	15
Frequency (GHz)	36	36	36
Bandwidth (MHz)	17.3	17.3	17.[illegible]
RF Transmit Power (dBW)	3	3	3
Transmitter and Receiver			
Antenna Size (m)	1	1	1
Antenna Gain (dB)	49	49	49
Losses Associated with Transmitter (dB)	1	1	1
Space Loss (dB)	137.6	143.6	147.1
Rainfall Attenuation (dB)	30	40	52.5
Loss due to other Propagation Effects (Scintillation, Gas, etc.)(dB)	3	4	5
Loss Associated with Receiver (dB)	1	1	1
Receiver Noise Figure (dB)	5	5	5
Receiver Noise Power (dBW)	-131.5	-131.5	-131.5
SNR @ 10^{-4} BER (dB)	12.7	12.7	12.7
System Margin (dB)	42.2	25.2	8.2

3.3.2.2 0.95 ETE Availability

The unavailability allocation to a 10 km millimeter wave LOS is 1.06×10^{-4}, where 8.8×10^{-5} is due to propagation outage and 1.8×10^{-5} is due to equipment failure.

Table 3-20 shows the maximum allowable outage rates and their corresponding rain attenuations for three different path lengths. The link budget analysis is shown in Table 3-21.

From the link budget analysis shown in Table 3-21, the path length 8 km is barely feasible with the required availability. Most links in Germany are longer than 10 km. Therefore, the longest possible repeater spacing, 8 km is proposed with 0.95 ETE availability requirement. This repeater spacing is not supposed to have any difficulty of maintaining given availability requirement, because the heavy rainfall (more than 30 mm/hr) affects a smaller region than 5 km diameter. The rain attenuation has been evaluated with the assumption that the rainfall rate is evenly distributed over the path which is longer than 5 km.

3.3.2.3 0.99 ETE Availability

As stated in Section 3.1.2, the unavailability for a 10 km millimeter wave LOS link has been specified as 5.3×10^{-5}, where 3.5×10^{-5} is due to propagation outage, and 1.8×10^{-5} is due to equipment failure. This requirement may be called standard availability for DCS III system under normal conditions. However, this unavailability was tentatively suggested until standard allocation to the millimeter LOS is officially decided. Unlike microwave LOS which is not greatly influenced by rainfall or lower ETE availability, millimeter wave LOS system will be difficult to achieve with long repeater spacing.

Table 3-22 shows the maximum allowable outage rates and their corresponding rain attenuations for three different path lengths.

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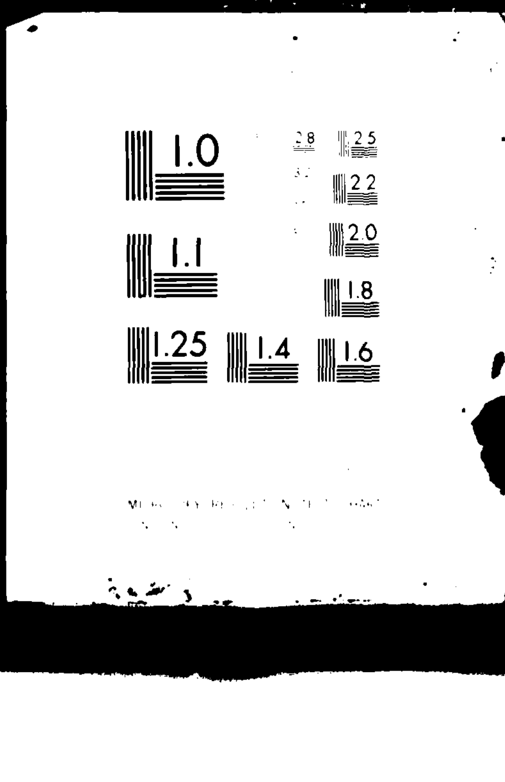

Table 3-20. Rainfall Attenuation and Propagation Outage for 0.95 ETE Availability

Path Length (km)	4	6	8
Propagation Outage	3.52×10^{-5}	5.28×10^{-5}	7.04×10^{-5}
Rainfall Rate (mm/hr)	55	47	31
Rain Attenuation Rate (dB/km)	13	10	8
Total Rain Attenuation (dB)	52	60	64

Table 3-21. Millimeter Wave LOS Link Analysis for 0.95 ETE Availability

PARAMETER	VALUE		
Path Length (km)	4	6	8
Frequency (GHz)	36	36	36
Bandwidth (MHz)	17.3	17.3	17.3
RF Transmit Power (dBW)	3	3	3
Transmitter and Receiver			
Antenna Size (m)	1	1	1
Antenna Gain (dB)	49	49	49
Losses Associated with Transmitter (dB)	1	1	1
Space Loss (dB)	135.7	139.2	141.7
Rainfall Attenuation (dB)	52	60	64
Loss due to other Propagation Effects (dB) (Scintillation, Gas, etc.)	2	3	4
Losses Associated with Receiver (dB)	1	1	1
Receiver Noise Figure (dB)	5	5	5
Receiver Noise Power (dBW)	-131.5	-131.5	-131.5
SNR @ 10^{-4} BER (dB)	12.7	12.7	12.7
System Margin (dB)	23.1	10.6	3.1

Table 3-22. Rainfall Attenuation and Propagation Outage for 0.99 ETE Availability

Path Length (km)	3.5	4.0	4.5
Propagation Outage	1.22×10^{-5}	1.4×10^{-5}	1.58×10^{-5}
Rainfall Rate (mm/hr)	77	74	72
Rain Attenuation Rate (dB/km)	18	17	16
Total Rain Attenuation (dB)	63	68	72

The link budget analysis is shown in Table 3-23. As the system with a path length of 45 km has 1.6 dB system margin,consequently, a longer path is not recommended for 0.99 ETE availability.

3.3.3 Millimeter Wave and Microwave Mixture Systems

Two different millimeter wave and microwave mixture systems have been proposed in the Phase II Task 1 Report (Ref. 1-3). One is that link topology be similar to that of the microwave LOS system with millimeter waves and microwaves proposed for short link paths and long path links, respectively. The other is that the topology be similar to that of the millimeter wave LOS system and microwaves and millimeter waves be designed to be alternative paths for each other in some important links, especially for wideband user links. The latter network may be superior to the first one in node to node link performance, as a microwave LOS is endurable in heavy rainfall conditions and millimeter wave can carry wider bandwidth information so that they can compensate each other's shortcomings.

Both proposed mix I and mix II system consist of microwave links and millimeter wave links. Therefore, performance of links can be re-evaluated using the methodology of either microwave system discussed in Section 3.3.1 or millimeter wave system discussed in Section 3.3.2.

Table 3-23. Millimeter Wave LOS Link Analysis for 0.99 ETE Availability

PARAMETER	VALUE		
Path Length (km)	3.5	4.0	4.5
Frequency (GHz)	36	36	36
Bandwidth (MHz)	17.3	17.3	17.3
RF Transmit Power (dBW)	3	3	3
Transmitter and Receiver			
Antenna Size (m)	1	1	1
Antenna Gain (dB)	49	49	49
Losses Associated with Transmitter (dB)	3	3	3
Space Loss (dB)	134.5	135.7	136.7
Rainfall Attenuation (dB)	63	68	72
Loss Due to Other Propagation Effects (dB) (Scintillation, Gas, etc.)	2.0	2.0	2.5
Losses Associated with Receiver (dB)	3	3	3
Receiver Noise Figure (dB)	5	5	5
Receiver Noise Power (dBW)	-131.5	-131.5	-131.5
SNR @ 10^{-4} BER (dB)	12.7	12.7	12.7
System Margin (dB)	9.3	3.1	2.4

If the performance of long links which consist of several nodes and a combination of microwaves and millimeter waves is required, it will be simply a combination of each link performance. For instance, availability will be the product of availability of each component link.

3.4 CONCLUDING REMARKS ON PERFORMANCE EVALUATIONS

The proposed Hawaii alternative and Central Germany alternative systems are re-evaluated in Sections 3.2 and 3.3, respectively. The re-evaluation is done on the link basis not network basis. Only three kinds of media were considered, namely, microwave LOS, millimeter wave LOS and fiber optic system.

Microwave LOS system has been widely used so that its performance characteristics are relatively well understood, and its standard is available. Hawaii microwave LOS system proposed a space diversity (10 m antenna vertical separation) for only 0.99 ETE availability case and non-diversity systems are proposed for the other two cases, 0.90 and 0.95 ETE. Germany microwave LOS systems have no difficulty to meet the required availability with varying antenna size and space diversity technique. For the lowest ETE availability requirement 0.90, a non-diversity system has been proposed to reduce the system cost. Different sizes of antenna have been proposed for links with different path lengths. For ETE availabilities 0.95 and 0.99, space diversity with two antennas vertically spaced at 5 m or 10 m have been proposed respectively. Space diversity combiners are proposed instead of switched space diversity for which switching is simply based on a threshold in the received signal (Ref. 3-6).

Since there are no standard availability allocations available for a millimeter wave LOS system, it has been tentatively proposed. From the performance evaluation done in Section 3.3.2, it is known that long terrestrial millimeter wave systems have difficulty maintaining high availability because of severe rainfall attenuation. If high availability is required for a link, one approach is path diversity in that two spatially separated millimeter wave links are deployed. The other is

that a complimentary microwave LOS link is employed in addition to the millimeter wave LOS link.

The first approach requires almost double channel capacity for each link. The later system may have less traffic capacity when microwave system is employed for a short time during which the millimeter wave link is out due to rainfall.

Without path diversity or complimentary microwave link, it is very difficult to have repeater spacing longer than 3 km and 5 km with 0.99 ETE availability for Hawaii and Germany, respectively.

Since optical fiber is rapidly developing, there is no available reliability record for optical device as well as optical trunk system. However, there is no serious problem to provide optical communication system satisfying the given availability in this decade.

4.0 STRESSED SYSTEM PERFORMANCE EVALUATION

The performance of all proposed transmission alternatives in a benign environment have been re-evaluated and presented in the last section. This section concerns the performance of these alternatives in a specified stressed condition. First the system measure, Average Network Availability (ANA) is defined and its methodology is discussed in Section 4.1. Then in Section 4.2, the developed method is applied to a sample example network to demonstrate the approach and computational procedure, with the numerical results presented. The next two sections present the evaluation results of proposed alternatives for Hawaii and Germany respectively. The last section provides a short description of the developed ANA program.

4.1 STRESSED NETWORK PERFORMANCE MEASURE

The adopted measure of communications system or network performance under a stressed condition is Average Network Availability (ANA). As stated in Phase II Task 1 Report (Ref. 1-3), the ANA has been suggested but not defined in the Phase II Effort Guidance. This measure has been developed with the government's consent in the performance period of Task 1. Some material of Task 1 Report is repeated here to provide the readers with the necessary background to appreciate the discussion and results presented in the following subsection.

In this subsection, the stressed condition is explained first and the ANA is defined and discussed. Then related assumptions adopted for and remarks on the ANA evaluation are presented.

4.1.1 Stressed Condition

There are many different kinds of threats which an enemy may apply to a communications link or network, for example, jamming, high altitude electromagnetic pulse (HEMP) attack, and various forms of physical attacks on a communications facility. Because of the difficulties of defining a threat scenario, and then analyzing the impact of the scenario on the communications systems, a stressed condition will be represented by the

deletion of transmission links from the communications network. If a node is attacked, all links connected to that node will be removed from the network.

For current work, random disruption of 10, 20, and 50 percent of links of a proposed network are considered for simulating stressed conditions.

4.1.2 Average Network Availability

Although "link availability" or average link availability can be defined in several different ways, by adopting a definition, the performance of a link can be computed or predicated theoretically or measured. Average network availability is a new concept which does not yet have a commonly accepted definition. In the context of the present work, ANA is defined in the following paragraphs.

All links of a network under consideration have a known link traffic in terms of number of voice channels or bit rate expressed in Mbps. A digitized voice channel is counted as 64 kbps. Each link has a 20 percent growth capacity or spare capacity if not specified, which will be used to re-route traffic in the most efficient way when the normal traffic flow is disrupted. Each link of the network also assumes a prorated link time availability (LTA) as discussed in Section 3.3 of Phase II Task 1 Report (Ref. 3-1). Each node contains the necessary multiplexer-demultiplexer and switching device for automatic traffic re-routing.

In a stressed condition with some randomly selected links having been removed, all surviving links are assumed to perform at least equal to or better than their specified LTA. Then all spare link capacities of surviving links will be used to re-route traffic of the disrupted links.

With the above assumptions in mind, then measures or terms related to network perform measure are defined. To be specific, consider a network consisting of n nodes and ℓ links. Let Ni, i = 1, 2, ..., n and Lj or Lj(h, k), j - 1, 2, ... ℓ, denote these nodes and

links respectively where h and k are the nodes, namely Nh and Nk connected by the Lj link. The link traffic and spare capacity of Lj link are denoted by LTj and LSj both in terms of number of voice channels or data rate in Mbps. Hence, the Total Network Link Traffic (TNLT) and the Total Network Spare Capacity (TNSC) are given by:

$$\mathrm{TNLT} = \sum_{j} \mathrm{LTj}, \qquad (4\text{-}1)$$

and

$$\mathrm{TNSC} = \sum_{j} \mathrm{LSj} \qquad (4\text{-}2)$$

respectively.

To simulate a stressed condition, a r-percent of number of links of the network, i.e.,

$$m = rn \text{ (a rounded integer)} \qquad (4\text{-}3)$$

links be deleted. Let these deleted links be Mp(q,t) and their link traffic and spare capacity be MTp and MSp. Then the Total Disrupted Link Traffic of the network is the summation of link traffic of all disrupted links, i.e.,

$$\mathrm{TDLT} = \sum_{p} \mathrm{MTp} \qquad (4\text{-}4)$$

The Network Traffic Disruption Rate (NTDR) is the fraction of link traffic being disrupted and is given by

$$\mathrm{NTDR} = \frac{\mathrm{TDLT}}{\mathrm{TNLT}} \qquad (4\text{-}5)$$

Apparently, NTDR does not equal to r in general. Not all disrupted link traffic, TDLT, is lost because part of the disrupted link traffic would be re-routed through the spare capacities of other surviving links. The

re-routed traffic for the disrupted link Mp is expressed as

$$RTp = RTp1 + RTp2 + \ldots .$$

Where RTp1, RTp2, . . . denote re-routed traffic through 1-relay, 2-relay, . . . respectively. Then the Total Re-routed Link Traffic (TRLT) is

$$TRLT = \sum_{p} RTp = \sum_{p} RTp1 + \sum_{p} RTp2 + \ldots . \quad (4\text{-}6)$$

and the re-routed Link Traffic Rate (RLTR) is

$$RLTR = \frac{TRLT}{TNLT} \quad (4\text{-}7)$$

The Network Traffic Reduction Rate (NTRR) is defined by

$$NTRR = \frac{TDLT - TRLT}{TNLT} \quad (4\text{-}8)$$

and gives the fraction of the net lost traffic.

Then the Network Availability (NA) for this specified condition is defined by

$$NA = \frac{\sum_{s} (LTs)\ (LTA) + \sum_{p} (RTp1)\ (LTA)^2 + \sum_{p} (RTp2)\ (LTA)^3 + \ldots}{(TNLT)\ (LTA)} \quad (4\text{-}9)$$

Where index s indicates all surviving links of the network. The above definition of NA assumes the same LTA for all links, otherwise, the corresponding LTAs will be used for the involved links.

The Average Network Availability (ANA) is the average of all NAs obtained by enough numbers of replications of the Monte Carlo method of deleting r-percent of total number of links.

Computing the ANA as defined above cannot be done manually because of the following reasons:

1. Search, identify, and record re-routing paths for even one link of a moderate size network is a time consuming process (see example network in Section 4.3.2)

2. Utilization of the Monte Carlo method to select links to be deleted implies the use of a random number generator.

3. The number of repliactions to provide statistically significant results of ANA is large. For example, for a moderate sized network consisting of 50 links, there is a total number of 126 trillion ways, 126,410,606,437,752 to be exact, to select 25 deleted links.

Therefore, a computer program needs to be developed. This program would continuously update the current ANA each time with a new NA generated by replication of the Monte Carlo method. This process would stop automatically until the updated ANA stabilized or the changes of successful ANAs are smaller than a specified limit. The developed computer program is described in Section 4.5.

4.1.3 Assumptions of ANA Methodology

It should be pointed out that the ANA so defined is for the purpose of comparing effectiveness of various proposed transmission alternatives under a specified stressed environment. Since a Monte Carlo method is utilized to select deleted links, the defined ANA is meaningful only for a complex network with a large number of links and enough number of Monte Carlo replications on NA evaluations.

Some major assumptions of this definition of ANA are listed below, some of them had already been discussed.

1. Each link is assumed with a known link traffic, spare capacity, and link time availability

2. In a stressed condition, the spare capacity of surviving links will be used for re-routing the traffic of disrupted links

3. Automatic re-routing, switching, multiplexer and demultiplexer equipment for re-routing traffic are assumed for each node

4. Optimal re-routing that the spare capacity of each surviving link is utilized to the extent possible is assumed. This minimizes the net lost traffic on the network traffic reduction rate.

5. All traffic is assumed to have equal priority.

4.1.4 Remarks on ANA Methodology

The ANA defined above is a usefull measure of network survivability. However, it should be pointed out that in each replication of Monte Carlo method, the resulting NA depends on the following factors:

- Network topology
- Link traffic and spare capacity of each link of the network
- Particular links assumed to be disrupted.

Furthermore, in the process of identifying re-routing paths and optimizing re-routed traffic, the following information will be revealed:

- Bottleneck of each re-routing path
- Links competed by different re-routing paths for one disrupted link
- Links competed by re-routing path for two or more different disruption links
- Topological feature of the network restricting re-routing and switching capability.

The above information is crucial for modifying the network to improve its survivability. An interactive computer program can be further developed, based on the ANA evaluation program mentioned already, to mechanize the process of improving network survivability.

4.2 EXAMPLE NETWORK AND NUMERICAL RESULTS

An example network is constructed and used for explaining the ANA methodology.

The developed CMANA program described in Section 4.5 is then applied to this example network. The intermediate and final computer results are then displayed here.

4.2.1 Example Network

An example network, as shown in Figure 4-1, consisting of six nodes and ten links has been adopted for this demonstration purpose. The link traffic and spare capacity of each link are tabulated in Table 4-1.

Note that a 20% spare capacity is assumed for each link, and the same LTA 0.999 is also assinged for all links. The total network traffic is 2,000 voice channels and total spare capacity is 400 voice channels.

4.2.2 Numerical Results by Inspection

Because of the small size of the example network, part of ANA computation can be done by inspection and the results are used to check the developed computer program. Working out the example network this way will not only exhibit the meaning of ANA but also reveal its salient features.

Consider a r=0.1, 10% damaged case. Assuming that Monte Carlo replication results the removal of link L2(1,3). Hence the total disrupted link traffic is 300 voice channels, i.e.,

$$TDLT = 300, \qquad (4-10)$$

and the network traffic disruption rate is,

$$NTDR = \frac{300}{2000} = 0.15 \qquad (4-11)$$

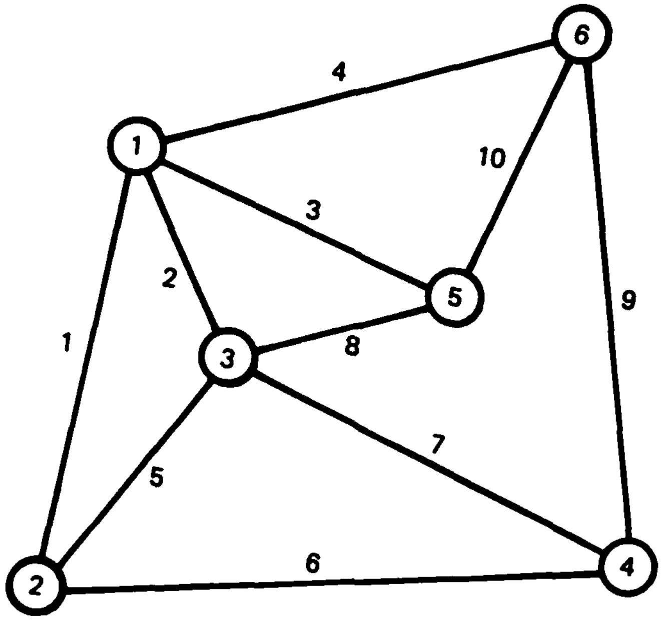

Figure 4-1. Example Network Configuration

Table 4-1. Example Network

LINK NO.	LINK END POINTS	LINK TRAFFIC (VOICE CHANNEL)	SPARE CAPACITY	ASSUMED LTA
1	1-2	200	40	0.999
2	1-3	300	60	0.999
3	1-5	100	20	0.999
4	1-6	300	60	0.999
5	2-3	150	30	0.999
6	2-4	250	50	0.999
7	3-4	250	50	0.999
8	3-5	200	40	0.999
9	4-6	150	30	0.999
10	5-6	100	20	0.999
		2,000	400	

Figure 4-2 displays the example network data input. Figures 4-3, and 4-4, *exhibit the first two monte* Carlo replications of 10% network damage. Each figure indicates the links being removed, L1(1,2) or L2(1,3), and its link traffic, and all re-routing paths selected with the number of voice channels being re-routed through. The last two lines give the network availability (NA) of the current case and the accumulated average network availability (ANA) respectively.

XXXXXXXXXX NETWORK XXXXXXXXXX

LINK NO.	END POINTS		LINK TRAFFIC (VOICE CH)	SPARE CHANNEL	ASSUMED LTA
1	1	2	200	40	.999
2	1	3	300	60	.999
3	1	5	100	20	.999
4	1	6	300	60	.999
5	2	3	150	30	.999
6	2	4	250	50	.999
7	3	4	250	50	.999
8	3	5	200	40	.999
9	4	6	150	30	.999
10	5	6	100	20	.999

Figure 4-2. Example Network Input Data Displayed by CMANA

Re-routing path searching and identification is a special feature of an capability of the developed ANA program. The following two figures demonstrate this capability. Figures 4-5 and 4-6 are computer listings of all possible re-routing paths for the removed link L1(1,2) and L2(1,3).

Since this example network consists of ten links, there are only ten Monte Carlo replications, each replication removing one link. The tenth replication results are shown in Figures 4-7 and 4-8, one for selected re-routing paths and channels, resulting NA, and ANA, and the other for all possible re-routing paths. Note that after all possible replication, the final ANA of the example network with 10% damage is 0.936.

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          1    2                 200 CHANNELS


REROUTING PATHS FOR LINK     1    2
PATH    1               1    3    2
                         30 CHANNELS
PATH    2               1    6    4    2
                         30 CHANNELS
PATH    3               1    3    4    2
                         20 CHANNELS


NETWORK AVAILIBILITY       .940
AVERAGE NETWORK AVAILIBILITY       .940
```

Figure 4-3. CMANA Display of Summarized ANA Analysis Results - First Replication of 10% Damage

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          1    3                 300 CHANNELS


REROUTING PATHS FOR LINK     1    3
PATH    1               1    2    3
                         30 CHANNELS
PATH    2               1    5    3
                         20 CHANNELS
PATH    3               1    6    4    3
                         30 CHANNELS
PATH    4               1    2    4    3
                         10 CHANNELS
PATH    5               1    6    5    3
                         20 CHANNELS


NETWORK AVAILIBILITY       .905
AVERAGE NETWORK AVAILIBILITY       .922
```

Figure 4-4. CMANA Display of Summarized ANA Analysis Results - Second Replication of 10% Damage

```
ROUTE NO. & NODES IN PATH

1
1   3   2

2
1   5   3   2

3
1   6   4   2

4
1   3   4   2

5
1   5   6   4   2

6
1   6   5   3   2

7
1   5   3   4   2

8
1   6   4   3   2

9
1   3   5   6   4   2

10
1   5   6   4   3   2

11
1   6   5   3   4   2
```

Figure 4-5. CMANA Display of Identified Re-routing Paths - First Replication of 10% Damage

```
ROUTE NO. & NODES IN PATH

1
1   2   3

2
1   5   3

3
1   6   4   3

4
1   2   4   3

5
1   6   5   3

6
1   6   4   2   3

7
1   5   6   4   3

8
1   5   6   4   2   3

9
1   2   4   6   5   3
```

Figure 4-6. CMANA Display of Identified Re-routing Paths - Second Replication of 10% Damage

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          5    6                  100 CHANNELS



REROUTING PATHS FOR LINK      5    6
PATH    1             5    1    6
                       20 CHANNELS
PATH    2             5    3    1    6
                       40 CHANNELS



NETWORK AVAILIBILITY        .980
AVERAGE NETWORK AVAILIBILITY        .936
```

Figure 4-7. CMANA Display of Summarized ANA Analysis Results - Last Replication of 10% Damage

```
ROUTE NO. & NODES IN PATH

 1
 5    1    6

 2
 5    3    1    6

 3
 5    3    4    6

 4
 5    3    2    1    6

 5
 5    1    2    4    6

 6
 5    1    3    4    6

 7
 5    3    2    4    6

 8
 5    1    2    3    4    6

 9
 5    3    1    2    4    6

10
 5    1    3    2    4    6

11
 5    3    4    2    1    6
```

Figure 4-8. CMANA Display of Identified Re-routing Paths - Last Replication of 10% Damage

For this example network, all possible re-routing paths for the disruption link, L2(1.3), can be found by inspection as follows:

Path 1;	1-5-3	(20), (40)
Path 2;	1-2-3	(40), (30)
Path 3;	1-2-4-3	(40), (50), (50)
Path 4;	1-6-5-3	(60), (20), (40)
Path 5;	1-6-4-3	(60), (30), (50)
Path 6;	1-6-4-2-3	(60), (30), (50), (30)
Path 7;	1-5-6-4-3	(20), (20), (30), (50)
Path 8;	1-5-6-4-2-3	(20), (20), (30), (50), (30)
Path 9;	1-2-4-6-5-3	(40), (50), (30), (20), (40)

However, the numbering of these re-routing paths is somewhat arbitrary. The re-routing path is indicated by the nodes involved, i.e., the path 1 is from node 1 to node 5 and then from node 5 to node 2. In other words, links L3(1,5) and L8(5,3) with spare capacity of 20 and 40 channels, as shown above form the re-routing path. The following observations can be made by examining the re-routing paths:

1. There is a bottleneck link for each re-routing path. The bottleneck link is the link with the least number of spare channels which determines the maximum number of traffic channels of the disrupted link that can be routed through the path.

2. Not all re-routing paths are available simultaneously because one link could be part of two or more re-routing paths.

An optimal choice of re-routing paths and their channels are found as follows:

Path 1;   20 channels, limited by the bottleneck link L3(1,5)

Path 2;   30 channels; limited by the bottleneck link L5(2,3)

Path 3;   10 channels; limited by link L1(1,2) shared with Path 2

Path 4;   20 channels; limited by the bottleneck link L10(5,6). This Path 1 share link L3(3,5) with Path 1.

Path 5;   30 channels; limited by the bottleneck link L9(4,6). This path share link L9(3,4) and link L4(1,6) with Path 3 and Path 4 respectively.

Note that those optimized re-routing paths are identified with those found by the CMANA program as shown in Figure 4-4. Hence, the 1-relay and 2-relay re-routed traffic are

$$RT_1 = 20 + 30 = 50 \tag{4-12}$$

$$RT_2 = 10 + 20 + 30 = 6 \tag{4-13}$$

respectively, and the total re-routed link traffic is

$$TRLT = 50 + 60 = 110 \tag{4-14}$$

Therefore, the network traffic reduction rate is

$$NTRR = \frac{300 - 110}{2000} = 0.095 \tag{4-15}$$

The network availability of this case is given by

$$NA = \frac{(1700)\ (0.999) + (50)\ (0.999)^2 + (60)\ (0.999)^3}{(2000)\ (0.999)} = 0.905 \tag{4-16}$$

This is the same ANA computized by the CMANA.

It is possible to evaluate the NA of this network by randomly removing one link each time, i.e., 10% disruption. The average of these ten NAs is then the ANA of this network with 10% damage. It is

a time consuming process hence omitted here. However, the computer program results an ANA of 0.936. (See Figure 4-8)

Next consider another case of 20% damage, i.e., removed two links, L8(3,5) and L10(5,6). This case results in the same total disrupted link traffic and network traffic disruption rate

$$TDLT = 300, \tag{4-17}$$

$$NTDR = 0.15 \tag{4-18}$$

as the first case. However, tnere is only one re-routing path each for the two disrupted links;

Path 1; 3-1-5, (60), (20), for Link L8(3,5)

Path 2; 5-1-6, (20), (60), for Link L10(5,6)

These two re-routing paths compete the 20 spare channels of link L3(1,5). This yields

$$NTRR = 0.14,$$

and

$$NA = 0.859.$$

It is worthwhile to point out that a 10-percent and a 20-percent damage case result in the same 15-percent total network disruption rate but different network availability of 0.944 and 0.859 respectively.

Two observations of this case are:

1. A surviving link can be competed by different disrupted links, i.e., this link would be used for re-routing traffic of two or more disrupted links.
2. The low ANA of this case is caused by the topologic feature of the network.

4.2.3 Numerical Results by ANA Program

The ANA program developed and described in Section 4.5 has been thoroughly tested. This program has been applied to the example network for final checking. Some computer print outs are displayed in the following figures:

A test run of the CMANA program for the example network with 30% damages has been conducted. Figures 4-9 and 4-10 show the summarized ANA analysis results of the first and the last replications. Figures 4-11 and 4-12 display identified re-routing paths for these two replications respectively. The final ANA of the example network, as shown in Figure 4-10, is 0.715 for 30% network damage.

Another feature of the CMANA program worthwhile to mention is the capability of automatic termination of the Monte Carlo replication process. This feature has been employed in the above mentioned 30% damage run.

The adopted criterion of termination is that the change between two consecutive ANA is less than 5% for five successive comparisons. Change of this criterion could be made later as more experience would be gained for running the program.

4.3 PERFORMANCE OF STRESSED HAWAII ALTERNATIVE TRANSMISSION SYSTEMS

There are three Hawaii alternative transmission systems to be evaluated for their performance under the stressed conditions with 10%, 20% and 50% network damage. However, the proposed microwave and millimeter wave LOS systems have the identical network topology and the same link traffic and spare capacity for all links, their performance under a stressed condition will be the same. One of them is evaluated and the results are applicable to both alternatives. In the following, these two systems are referred to as Hawaii LOS system.

4.3.1 Hawaii LOS System

The network topology of Hawaii LOS system is shown in Figure 4-13. Figure 4-14 displays the computer print out of ANA analysis input data. The ANA analysis results are summarized in Table 4-2. Figures 4-15 and 4-16 exhibit summarized ANA results and identified re-routing paths for the last replication of the 10% network damage case.

Note that the Hawaii LOS system consists of only 13 nodes and is a very small network. Furthermore, the network composes only 22 links, less than one third of the total number of links of a fully connected network of 13 nodes. A fully connected network is a network of which

```
30.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          3    5                    200 CHANNELS
LINK          6    4                    150 CHANNELS
LINK          5    1                    100 CHANNELS


REROUTING PATHS FOR LINK     3    5
THERE IS NO PATH BETWEEN     3 &       5.


REROUTING PATHS FOR LINK     6    4
PATH    1              6    1    2    4
                          40 CHANNELS


REROUTING PATHS FOR LINK     5    1
PATH    1              5    6    1
                          20 CHANNELS


NETWORK AVAILIBILITY        .805
AVERAGE NETWORK AVAILIBILITY        .805
```

Figure 4-9. CMANA Display of Summarized ANA Analysis Results - First Replication of 30% Damage

```
30.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          6    1                    300 CHANNELS
LINK          1    3                    300 CHANNELS
LINK          5    6                    100 CHANNELS


REROUTING PATHS FOR LINK     6    1
PATH    1              6    4    2    1
                          10 CHANNELS


REROUTING PATHS FOR LINK     1    3
PATH    1              1    2    3
                          30 CHANNELS
PATH    2              1    5    3
                          20 CHANNELS


REROUTING PATHS FOR LINK     5    6
PATH    1              5    3    4    6
                          20 CHANNELS


NETWORK AVAILIBILITY        .690
AVERAGE NETWORK AVAILIBILITY        .715
```

Figure 4-10. CMANA Display of Summarized ANA Analysis Results - Last Replication of 30% Damage

```
ROUTE NO. & NODES IN PATH

1
3   1   6   5

2
3   2   1   6   5

3
3   4   2   1   6   5

4
6   1   2   4

5
6   1   3   4

6
6   1   2   3   4

7
6   1   3   2   4

8
5   6   1
```

Figure 4-11. CMANA Display of Identified Re-routing Paths - First Replication of 30% Damage

```
ROUTE NO. & NODES IN PATH

1
6   4   2   1

2
6   4   3   2   1

3
6   4   3   5   1

4
6   4   2   3   5   1

5
1   2   3

6
1   5   3

7
1   2   4   3

8
5   3   4   6

9
5   1   2   4   6

10
5   3   2   4   6

11
5   1   2   3   4   6
```

Figure 4-12. CMANA Display of Identified Re-routing Paths - Last Replication of 30% Damage

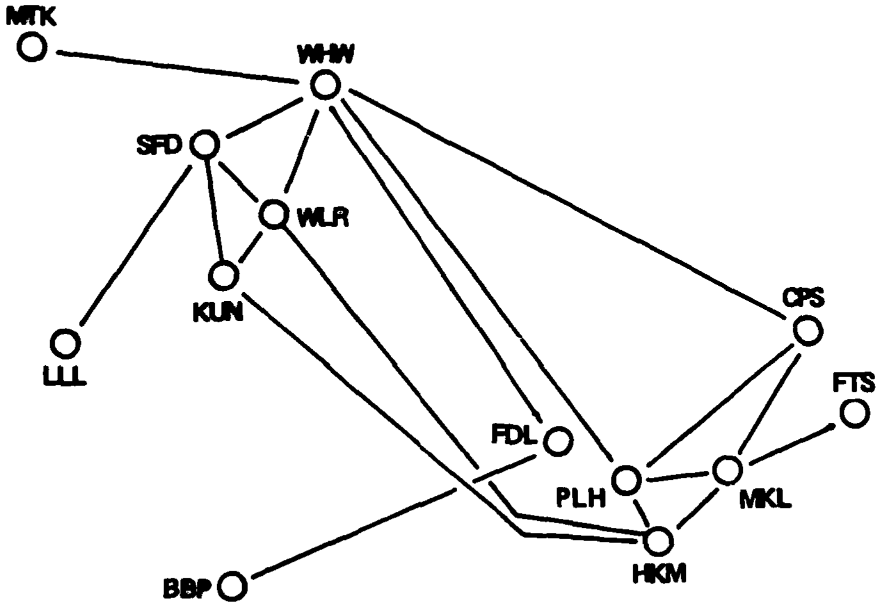

Figure 4-13. Hawaii LOS System Network Topology

XXXXXXXXXX NETWORK XXXXXXXXXX

LINK NO.	END POINTS		LINK TRAFFIC (VOICE CH)	SPARE CHANNEL	ASSUMED LTA
1	1	4	144	48	.999
2	2	3	144	48	.999
3	3	4	312	72	.999
4	3	5	144	48	.999
5	3	6	144	48	.999
6	4	6	456	120	.999
7	4	8	456	120	.999
8	4	9	144	48	.999
9	4	12	312	72	.999
10	4	14	456	120	.999
11	5	6	312	72	.999
12	5	13	192	48	.999
13	6	13	144	48	.999
14	7	12	312	72	.999
15	8	9	144	48	.999
16	8	11	456	120	.999
17	8	12	144	48	.999
18	8	13	456	120	.999
19	9	11	312	72	.999
20	10	11	312	72	.999
21	11	13	144	48	.999
22	12	14	144	48	.999

Figure 4-14. Hawaii LOS System Network Input Data Displayed by CMANA

Table 4-2. ANA Analysis Results of Hawaii LOS System

Total Number of Nodes	13		
Total Number of Links	22		
Total Network Link Traffic (TNLT) (Voice Channels)	5784		
Total Network Spare Capacity (TNSC) (Voice Channels)	1560		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	2	4	10
Average Total Network Traffic Disruption Rate (ANTDR)	0.0809	0.178	0.443
Average Total Re-routed Link Traffic Rate (ARLTR)	0.0297	0.036	0.021
Average Total Network Reduction Rate (ANTRR)	0.0518	0.142	0.432
Average Network Availability (ANA)	0.946	0.850	0.557

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          3    5                  144 CHANNELS
LINK         11   13                  144 CHANNELS


REROUTING PATHS FOR LINK      3    5
PATH    1             3    6    5
                       48 CHANNELS
PATH    2             3    4    6    5
                       24 CHANNELS
PATH    3             3    4    6   13    5
                       48 CHANNELS


REROUTING PATHS FOR LINK     11   13
PATH    1            11    8   13
                      120 CHANNELS


NETWORK AVAILIBILITY        .991
AVERAGE NETWORK AVAILIBILITY        .946
```

Figure 4-15. CMANA Display of Summarized ANA Results - Last Replication of 10% Damage Case of Hawaii LOS System

ROUTE NO. & NODES IN PATH

1
3 6 5

2
3 4 6 5

3
3 6 13 5

4
3 4 6 13 5

5
3 4 8 13 5

6
3 4 9 8 13 5

7
3 6 4 8 13 5

8
3 4 8 13 6 5

9
3 4 12 8 13 5

10
3 6 4 9 8 13 5

11
3 4 9 11 8 13 5

(Continued on Right-Hand Side)

12
3 4 9 8 13 6 5

13
3 6 4 12 8 13 5

14
3 4 12 8 13 6 5

15
3 6 4 9 11 8 13 5

16
3 4 9 11 8 13 6 5

17
11 8 13

18
11 9 8 13

19
11 8 4 6 13

20
11 9 4 6 13

21
11 9 4 8 13

22
11 8 9 4 6 13

(Continued on Next Page)

Figure 4-16. CMANA Display of Identified Re-routing Paths - Last Replication of 10% Damage Case of Hawaii LOS System

23
11 8 12 4 6 13

24
11 9 8 4 6 13

25
11 8 4 3 6 13

26
11 8 4 6 5 13

27
11 9 4 3 6 13

28
11 9 4 6 5 13

29
11 9 4 12 8 13

30
11 8 4 3 6 5 13

31
11 9 4 3 6 5 13

32
11 9 8 12 4 6 13

33
11 8 9 4 3 6 13

34
11 8 9 4 6 5 13

35
11 8 12 4 3 6 13

36
11 8 12 4 6 5 13

37
11 9 8 4 3 6 13

38
11 9 8 4 6 5 13

39
11 8 9 4 3 6 5 13

40
11 8 12 4 3 6 5 13

41
11 9 8 4 3 6 5 13

42
11 9 8 12 4 3 6 13

43
11 9 8 12 4 6 5 13

44
11 9 8 12 4 3 6 5 13

(Continued on Right-Hand Side)

Figure 4-16. CMANA Display of Identified Re-routing Paths - Last Replication of 10% Damage Case of Hawaii LOS System

every node is directly connected to all other nodes. If the 13 nodes Hawaii LOS network is a fully connected network, it would be composed of

$$C_2^{13} = \frac{13 \cdot 12}{2 \cdot 1} = 78$$

links.

Even for this small and not fully connected network, identifying re-routing paths is a difficult task. Figure 4-16, results of the last Monte Carlo replication of the CMANA program, demonstrates the needed effort of such a task. That figure lists 16 and 28 re-routing paths for the disrupted links L4(3,5) and L21(11,13) respectively. These listed paths are the only possible re-routing paths for these two deleted links. This fact can be verified by carefully examining the network topology shown in Figure 4-13. The capability of searching and recording all possible re-routing paths for each of the disrupted links in a systematic way is the major and most crucial accomplishment of CMANA program development. This capability has been thoroughly tested and checked using the example network, Hawaii alternatives, and Central Germany alternatives.

Although 16 and 28 re-routing paths have been identified for disrupted links L4(3,5) and L21(11,13), only 120 voice channels can be re-routed through three paths (path Nos. 1, 2, and 5 of Figure 4-16) and one path (path No. 17 of Figure 4-16) for the L4 and L21 link respectively. This is an expected fact rather than a surprising finding as discussed in the Section 4.1.4 Remarks On ANA Methodology.

By inspecting the topology of the Hawaii LOS network as shown in Figure 4-14, it is obvious that all re-routing paths for the disrupted link L4(3,5) have to pass through either link L11(5,6) or link L12(5,13) to reach the node N5. Among the identified re-routing paths for the link L4, path Nos. 1, 2, 8, 10, 12, 14 and 16 all compete the link L11(5,6) with spare capacity of 72 channels. The shortest path, path No. 1 (3-6-5) was chosen by the CMANA program first, and the bottleneck of this path is link L5(3,6) which limits the re-routed capacity of this path to 48 channels. Then the next shortest path, path No. 2 (3-4-6-5) was choosen to fully utilize the remaining spare capacity of 24 channels of

Link L11(6,5). All other re-routing paths, Nos. 3 to 7 inclusive, 9, 11, 13, and 15, compete the link L12(5,13) with spare capacity of 120 channels; CMANA chosen one of the two shortest paths, path No. 3 (3-4-6-13-5). The total re-routed traffic through this path is 48 channels which is limited by sharing the spare capacity of link L3(3,4) with the re-routing path No. 2.

For the second disrupted link L21(11,13), CMANA program identified 28 re-routing paths (Nos. 18 to 44 inclusive) which can be classified into three groups. This first one consists of four paths, path Nos. 17, 18, 21, and 29, and these paths compete the link L18(8,13). The shortest one-rely path, No. 1(11-8-13) was choosen to re-route 120 channels of traffic of the disrupted link L21(11,13). The second group consists of 12 paths competing the link L13(6,13), and the third group consists of 12 paths competing the link L12(5-13). Nevertheless, no traffic of the disrupted link L21(11,13) can be re-routed through any path of either the second or third group. It is because spare capacity of both links L13(6,13) and L12(5,13) has been allocated to re-route the traffic of the first disrupted link L4(3,5) already.

The developed CMANA program does not consider priority of either the traffic involved or the disrupted link. Re-routing of the disrupted link traffic is optimal in such a sense that the paths with the least number of relays are considered first as an alternative path for the deleted link. Orders are arbitrary when two or more paths for the same disrupted link have the same number of relays. In the case of two or more disrupted links, the link selected first for deletion by the random number generator will be considered first for re-routing. In this example, all the 1-relay paths for link L4(3,5) will be considered first, and then followed by all the 1-relay paths for link L2(11,13), all the 2-relay paths for link L4(3,5), and all the 2-relay paths for link L21(11,13). The process continues until all the possible paths have been checked or all the disrupted links have been re-routed.

Figures 4-17, 4-18, 4-19, and 4-20 exhibit the similar information for the 20% and 50% network damage cases respectively.

```
20.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          4    3                 312 CHANNELS
LINK          3    5                 144 CHANNELS
LINK         12    7                 312 CHANNELS
LINK         11   13                 144 CHANNELS


REROUTING PATHS FOR LINK     4    3
PATH    1            4    6    3
                        48 CHANNELS


REROUTING PATHS FOR LINK     3    5
THERE IS NO PATH BETWEEN     3 &      5.


REROUTING PATHS FOR LINK    12    7
THERE IS NO PATH BETWEEN    12 &      7.


REROUTING PATHS FOR LINK    11   13
PATH    1           11    8   13
                       120 CHANNELS
PATH    2           11    9    4    6   13
                        24 CHANNELS

NETWORK AVAILIBILITY       .869
AVERAGE NETWORK AVAILIBILITY       .850
```

Figure 4-17. CMANA Display of Summarized ANA Results - Last Replication of 20% Damage of Hawaii LOS System

```
ROUTE NO. & NODES IN PATH

 1                                       9
 4   6   3                               4   9  11   8  13   5   6   3

 2                                      10
 4   8  13   6   3                       3   6   5

 3                                      11
 4   8  13   5   6   3                   3   6  13   5

 4                                      12
 4   9   8  13   6   3                   3   6   4   8  13   5

 5                                      13
 4  12   8  13   6   3                   3   6   4   9   8  13   5

 6                                      14
 4   9   8  13   5   6   3               3   6   4  12   8  13   5

 7                                      15
 4  12   8  13   5   6   3               3   6   4   9  11   8  13   5

 8
 4   9  11   8  13   6   3              THERE IS NO PATH BETWEEN   12 &   7.
```

(Continued on Right-Hand Side)

(Continued on Next Page)

Figure 4-18. CMANA Display of Identified Re-routing Paths - Last Replication of 20% Damage Case of Hawaii LOS System

16
11 8 13

17
11 9 8 13

18
11 8 4 6 13

19
11 9 4 6 13

20
11 9 4 8 13

21
11 9 4 12 8 13

22
11 8 9 4 6 13

23
11 8 12 4 6 13

24
11 9 8 4 6 13

25
11 8 4 6 5 13

26
11 9 4 6 5 13

27
11 9 8 12 4 6 13

28
11 8 9 4 6 5 13

29
11 8 12 4 6 5 13

30
11 9 8 4 6 5 13

31
11 9 8 12 4 6 5 13

(Continued on Right-Hand Side)

Figure 4-18. CMANA Display of Identified Re-routing Paths - Last Replication of 20% Damage Case of Hawaii LOS System

```
50.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK         12    4                     312 CHANNELS
LINK          9   11                     312 CHANNELS
LINK         10   11                     312 CHANNELS
LINK          8   13                     456 CHANNELS
LINK          1    4                     144 CHANNELS
LINK          3    2                     144 CHANNELS
LINK         13    6                     144 CHANNELS
LINK          6    3                     144 CHANNELS
LINK          5   13                     192 CHANNELS
LINK          8   12                     144 CHANNELS


REROUTING PATHS FOR LINK    12    4
THERE IS NO PATH BETWEEN    12 &     4.


REROUTING PATHS FOR LINK     9   11
PATH    1             9    8   11
                       48 CHANNELS
PATH    2             9    4    8   11
                       24 CHANNELS


REROUTING PATHS FOR LINK    10   11
THERE IS NO PATH BETWEEN    10 &    11.

REROUTING PATHS FOR LINK     8   13
PATH    1             8   11   13
                       48 CHANNELS
```
(Continued on right-hand side)

```
REROUTING PATHS FOR LINK     1    4
THERE IS NO PATH BETWEEN     1 &      4.


REROUTING PATHS FOR LINK     3    2
THERE IS NO PATH BETWEEN     3 &      2.


REROUTING PATHS FOR LINK    13    6
THERE IS NO PATH BETWEEN    13 &      6.


REROUTING PATHS FOR LINK     6    3
PATH    1             6    4    3
                       72 CHANNELS
PATH    2             6    5    3
                       48 CHANNELS


REROUTING PATHS FOR LINK     5   13
THERE IS NO PATH BETWEEN     5 &     13.


REROUTING PATHS FOR LINK     8   12
THERE IS NO PATH BETWEEN     8 &     12.


NETWORK AVAILIBILITY      .624
AVERAGE NETWORK AVAILIBILITY      .557
```

Figure 4-19. CMANA Display of Summarized ANA Results - Last Replication of 50% Damage Case for Hawaii LOS System

```
ROUTE NO. & NODES IN PATH


THERE IS NO PATH BETWEEN   12 &    4.

   1
   9    8   11

   2
   9    4    8   11


THERE IS NO PATH BETWEEN   10 &   11.

   3
   8   11   13


THERE IS NO PATH BETWEEN    1 &    4.


THERE IS NO PATH BETWEEN    3 &    2.

   4
  13   11    8    4    6

   5
  13   11    8    9    4    6
```

(Continued on right-hand side)

```
   6
  13   11    8    4    3    5    6

   7
  13   11    8    9    4    3    5    6

   8
   6    4    3

   9
   6    5    3

  10
   5    3    4    8   11   13

  11
   5    6    4    8   11   13

  12
   5    3    4    9    8   11   13

  13
   5    6    4    9    8   11   13


THERE IS NO PATH BETWEEN    8 &   12.
```

Figure 4-20. CMANA Display of Identified Re-routing Paths - Last Replication of 50% Damage Case for Hawaii LOS System

4.3.2 Hawaii Fiber Optic System

The network topology of the proposed fiber optic system is shown in Figure 4-21. Figure 4-22 displays the CMANA program input data print out. The performance of the system has been evaluated for 10%, 20%, and 50% network damage cases. The results are tabulated in Table 4-3.

The computer print out of the summarized ANA analysis results and identified re-routing paths for the last replication are reproduced in Figures 4-23 to 4-28 inclusive for the 10%, 20% and 50% network damage cases.

4.4 PERFORMANCE OF CENTRAL GERMANY STRESSED ALTERNATIVE TRANSMISSION SYSTEMS

The developed CMANA program has also been employed to evaluate the performance of proposed alternative transmission systems in Central Germany. The results are presented in this section.

4.4.1 Central Germany Microwave LOS System

The network topology of the proposed microwave LOS system is shown in Figure 4-29. The connectivity table of this network is shown in Figure 4-30, display of CMANA input data. Table 4-4 summarizes the evaluation results of the proposed microwave LOS system performance under 10%, 20%, and 50% damage conditions.

The last Monte Carlo replication results for three damage cases are presented in Figures 4-31, 4-32 and 4-33 respectively. However, all displays of identified re-routing paths have been omitted.

4.4.2 Central Germany Millimeter Wave LOS System

The topology of the proposed millimeter wave LOS system is depicted in Figure 4-34. The connectivity of this transmission alternative is shown by the displayed CMANA input data as shown in Figure 4-35. The results of such analyses are tabulated in Table 4-5. The summarized ANA analysis results of 10%, 20% and 50% damage cases are exhibited by the facsimile reproductions of the computer print out as shown in Figures 4-36 to 4-38.

4.4.3 Central Germany Microwave and Millimeter Wave Mix I

Figure 4-39 shows the topology of the proposed microwave and millimeter wave mix system I. The connectivity of network can be seen from Figure 4-40, a reproduction of CMANA input data. The ANA analysis results are summarized in Table 4-6. The facsimile reproduction of computer print out of summarized ANA analyses results of three damages cases are displayed in Figures 4-41, 4-42, and 4-43.

4.4.4 Central Germany Microwave and Millimeter Wave Mix II

The topology of Germany microwave and millimeter wave Mix II system is depicted in Figure 4-44 and its connectivity is shown in Figure 4-45. This system has been evaluated for its performance under 10%, 20%, and 30% network damage conditions. The results are summarized in Table 4-7. The summarized ANA analysis results of the last replication of three cases are displayed in Figures 4-46, 4-47, and 4-48 respectively.

4.5 COMPUTER MODELING OF AVERAGE NETWORK AVAILABILITY ANALYSIS

A computer program has been designed and implemented for computing the average network availability for a disrupted network and is designated as CMANA Simulation Program. The Monte Carlo method is used to select the deleted links. The program is implemented in FORTRAN and is designed to run on the TRW/Time-Sharing System.

The definition, computing methodology, and the assumptions of ANA are described in Section 4.1.2 and 4.1.3 respectively. This section presents a description of the CMANA program. The CMANA consists of a main program, REROUTE, and four subroutines: DATA, DAMAGE, PATH and NEAVIL. They are discussed in the following subsections.

4.5.1 Main Program REROUTE

Program REROUTE is the main driver for the CMANA program. The REROUTE assumes that an input data file has been created prior to the execution of REROUTE. The file includes the data on the network topology, the link traffic and spare capacity of each link, the assumed LTA for each link and the percentage of links of the network to be disrupted.

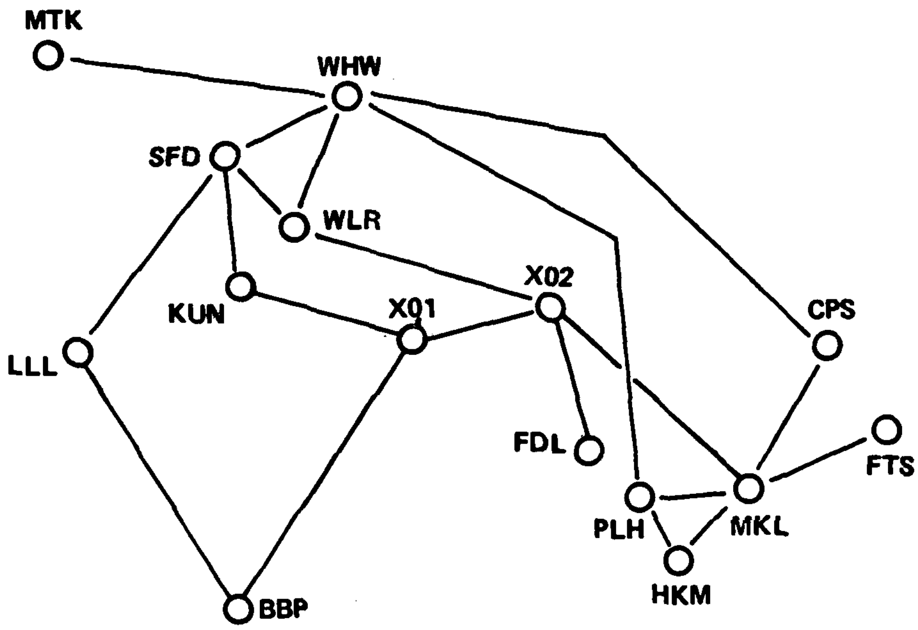

Figure 4-21. Hawaii Fiber Optic System Network Topology

XXXXXXXXXX NETWORK XXXXXXXXXX

LINK NO.	END POINTS		LINK TRAFFIC (VOICE CH)	SPARE CHANNEL	ASSUMED LTA
1	1	3	144	48	.999
2	2	3	312	72	.999
3	2	5	312	72	.999
4	2	6	312	72	.999
5	2	13	144	48	.999
6	3	6	624	144	.999
7	3	8	312	72	.999
8	3	14	456	120	.999
9	4	12	312	72	.999
10	4	13	144	48	.999
11	5	12	144	48	.999
12	6	7	144	48	.999
13	7	10	144	48	.999
14	7	12	456	120	.999
15	7	15	456	120	.999
16	8	9	144	48	.999
17	8	10	624	144	.999
18	9	10	312	72	.999
19	10	11	312	72	.999
20	10	14	456	120	.999
21	11	14	456	120	.999

Figure 4-22. Hawaii Fiber Optic System Network Input Data Displayed by CMANA

Table 4-3. ANA Analysis Results of Hawaii Fiber Optic System

Total Number of Nodes	13		
Total Number of Links	21		
Total Network Link Traffic (TNLT) (Voice Channels)	6720		
Total Network Spare Capacity (TNSC) (Voice Channels)	1728		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	2	4	10
Average Total Network Traffic Disruption Rate (ANTDR)	0.102	0.244	0.490
Average Total Re-routed Link Traffic Rate (ARLTR)	0.089	0.032	0.024
Average Total Network Reduction Rate (ANTRR)	0.088	0.212	0.466
Average Network Availability (ANA)	0.912	0.818	0.534

Note: To facilitate the analysis, the two cable junctions are treated as nodes.

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          2   13                    144 CHANNELS
LINK         12    4                    312 CHANNELS


REROUTING PATHS FOR LINK     2   13
THERE IS NO PATH BETWEEN     2 &    13.


REROUTING PATHS FOR LINK    12    4
THERE IS NO PATH BETWEEN    12 &     4.


NETWORK AVAILIBILITY       .932
AVERAGE NETWORK AVAILIBILITY       .912
```

Figure 4-23. CMANA Display of Summarized ANA Results - Last Replication of 10% Damage Case for Hawaii Fiber Optic System

```
ROUTE NO. & NODES IN PATH


THERE IS NO PATH BETWEEN     2 &    13.


THERE IS NO PATH BETWEEN    12 &     4.
```

Figure 4-24. CMANA Display of Identified Re-routing Paths - Last Replication of 10% Damage Case for Hawaii Fiber Optic System

```
20.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          8    3                    312 CHANNELS
LINK          1    3                    144 CHANNELS
LINK          5    2                    312 CHANNELS
LINK         11   10                    312 CHANNELS


REROUTING PATHS FOR LINK     8    3
PATH    1              8   10    7    6    3
                      48 CHANNELS


REROUTING PATHS FOR LINK     1    3
THERE IS NO PATH BETWEEN     1 &     3.


REROUTING PATHS FOR LINK     5    2
PATH    1              5   12    4   13    2
                      48 CHANNELS


REROUTING PATHS FOR LINK    11   10
PATH    1             11   14   10
                     120 CHANNELS


NETWORK AVAILIBILITY       .871

AVERAGE NETWORK AVAILIBILITY      .818
```

Figure 4-25. CMANA Display of Summarized ANA Analysis Results - Last Replication of 20% Damage Case For Hawaii Fiber Optic System

```
ROUTE NO. & NODES IN PATH

  1
  8  10  14   3

  2
  8  10   7   6   3

  3
  8   9  10  14   3

  4
  8   9  10   7   6   3

  5
  8  10   7   6   2   3

  6
  8   9  10   7   6   2   3

  7
  8  10   7  12   4  13   2   3

  8
  8   9  10   7  12   4  13   2   3

  9
  8  10   7  12   4  13   2   6   3

 10
  8   9  10   7  12   4  13   2   6   3
```

(Continued on right-hand side)

```
THERE IS NO PATH BETWEEN    1 &    3.

 11
  5  12   4  13   2

 12
  5  12   7   6   2

 13
  5  12   7   6   3   2

 14
  5  12   7  10  14   3   2

 15
  5  12   7  10  14   3   6   2

 16
 11  14  10

 17
 11  14   3   6   7  10

 18
 11  14   3   2   6   7  10

 19
 11  14   3   2  13   4  12   7  10

 20
 11  14   3   6   2  13   4  12   7  10
```

Figure 4-26. CMANA Display of Identified Re-routing Paths - Last Replication of 20% Damage Case For Hawaii Fiber Optic System

```
50.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK           3    2                     312 CHANNELS
LINK           6    3                     624 CHANNELS
LINK           2    6                     312 CHANNELS
LINK          12    5                     144 CHANNELS
LINK          10    9                     312 CHANNELS
LINK          10   11                     312 CHANNELS
LINK           1    3                     144 CHANNELS
LINK           2    5                     312 CHANNELS
LINK          14   10                     456 CHANNELS
LINK           6    7                     144 CHANNELS


REROUTING PATHS FOR LINK     3    2
THERE IS NO PATH BETWEEN     3 &     2.


REROUTING PATHS FOR LINK     6    3
THERE IS NO PATH BETWEEN     6 &     3.


REROUTING PATHS FOR LINK     2    6
THERE IS NO PATH BETWEEN     2 &     6.


REROUTING PATHS FOR LINK    12    5
THERE IS NO PATH BETWEEN    12 &     5.
```

(Continued on right-hand side)

```
REROUTING PATHS FOR LINK    10    9
PATH    1              10    8    9
                          48 CHANNELS


REROUTING PATHS FOR LINK    10   11
THERE IS NO PATH BETWEEN    10 &    11.


REROUTING PATHS FOR LINK     1    3
THERE IS NO PATH BETWEEN     1 &     3.


REROUTING PATHS FOR LINK     2    5
THERE IS NO PATH BETWEEN     2 &     5.


REROUTING PATHS FOR LINK    14   10
PATH    1              14    3    8   10
                          72 CHANNELS


REROUTING PATHS FOR LINK     6    7
THERE IS NO PATH BETWEEN     6 &     7.


NETWORK AVAILIBILITY        .561
AVERAGE NETWORK AVAILIBILITY       .534
```

Figure 4-27. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Hawaii Fiber Optic System

```
ROUTE NO. & NODES IN PATH

  1
  3    8   10    7   12    4   13    2


THERE IS NO PATH BETWEEN     6 &      3.


THERE IS NO PATH BETWEEN     2 &      6.


THERE IS NO PATH BETWEEN    12 &      5.

  2
 10    8    9

  3
 10    8    3   14   11


THERE IS NO PATH BETWEEN     1 &      3.


THERE IS NO PATH BETWEEN     2 &      5.

  4
 14    3    8   10

THERE IS NO PATH BETWEEN     6 &      7.
```

Figure 4-28. CMANA Display of Identified Re-routing Paths - Last Replication of 50% Damage Case for Hawaii Fiber Optic System

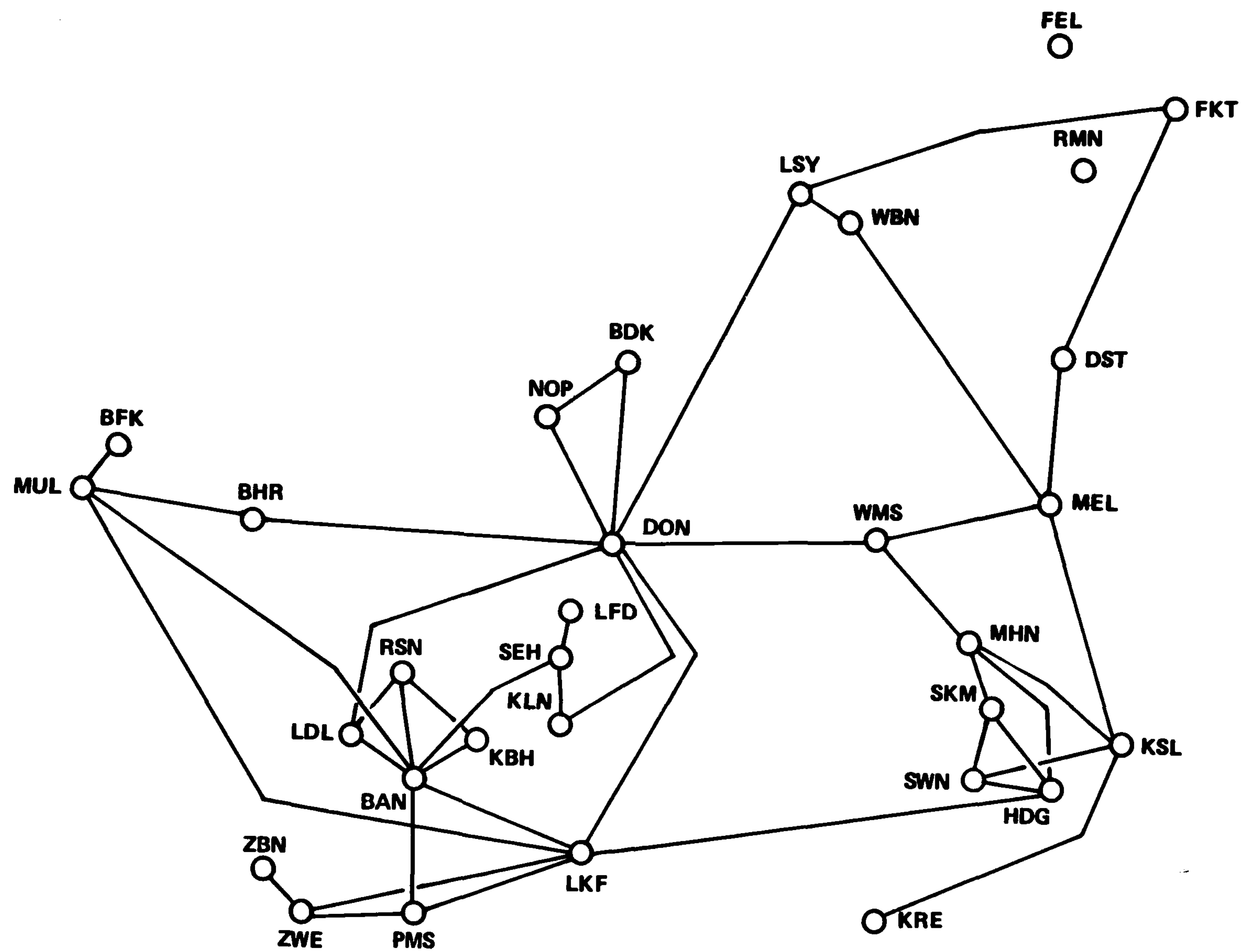

Figure 4-29. Central Germany Microwave LOS System Network Topology

XXXXXXXXXX NETWORK XXXXXXXXXX

LINK NO.	END POINTS		LINK TRAFFIC (VOICE CH)	SPARE CHANNEL	ASSUMED LTA
1	1	9	120	24	.999
2	1	13	144	24	.999
3	1	15	48	0	.999
4	1	20	288	72	.999
5	1	21	312	72	.999
6	1	22	288	72	.999
7	1	27	408	96	.999
8	2	5	72	24	.999
9	2	24	48	0	.999
10	3	20	1[illegible]4	24	.999
11	4	5	72	24	.999
12	4	20	192	48	.999
13	5	10	360	96	.999
14	5	13	312	72	.999
15	5	15	468	120	.999
16	5	23	96	24	.999
17	5	24	48	24	.999
18	5	25	146	24	.999
19	6	16	96	24	.999
20	6	29	48	0	.999
21	7	16	48	0	.999
22	7	23	48	0	.999
23	8	15	312	72	.999
24	8	17	48	24	.999
25	8	18	120	24	.999
26	8	26	288	72	.999
27	9	22	120	24	.999
28	10	27	312	72	.999

(Continued on right-hand side)

29	11	12	72	24	.999
30	12	16	96	24	.999
31	12	17	144	24	.999
32	12	26	144	24	.999
33	13	22	144	48	.999
34	14	27	28	8	.999
35	15	20	216	48	.999
36	15	21	312	72	.999
37	15	28	192	48	.999
38	16	25	48	24	.999
39	17	18	120	24	.999
40	17	25	108	24	.999
41	18	26	120	24	.999
42	19	28	96	24	.999
43	21	28	96	24	.999
44	23	29	48	0	.999

Figure 4-30. Germany Microwave LOS System Network Input Data Displayed by CMANA

Table 4-4. ANA Analysis Results of Germany Microwave LOS System

Total Number of Nodes	29		
Total Number of Links	44		
Total Network Link Traffic (TNLT) (Voice Channels)	6990		
Total Network Spare Capacity (TNSC) (Voice Channels)	1544		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	4	8	22
Average Total Network Traffic Disruption Rate (ANTDR)	0.069	0.189	0.502
Average Total Re-routed Link Traffic Rate (ARLTR)	0.017	0.024	0.012
Average Total Network Reduction Rate (ANTRR)	0.052	0.164	0.490
Average Network Availability (ANA)	0.948	0.835	0.510

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          27   10                 312 CHANNELS
LINK           5   23                  96 CHANNELS
LINK           4    5                  72 CHANNELS
LINK          25    5                 146 CHANNELS


REROUTING PATHS FOR LINK     27    10
PATH     1            27     1   13     5    10
                          24 CHANNELS
PATH     2            27     1   21    15     5    10
                          48 CHANNELS
PATH     3            27     1   22    13     5    10
                          24 CHANNELS


REROUTING PATHS FOR LINK      5    23
THERE IS NO PATH BETWEEN      5 &    23.


REROUTING PATHS FOR LINK      4     5
PATH     1              4   20   15     5
                          48 CHANNELS
```

(Continued on right-hand side)

```
REROUTING PATHS FOR LINK     25     5
PATH     1              25   17    8   15    5
                             24 CHANNELS

NETWORK AVAILIBILITY          .934
AVERAGE NETWORK AVAILIBILITY        .948
```

Figure 4-31. CMANA Display of Summarized ANA Analysis Results - Last Replication of 10% Damage Case for Germany Microwave LOS System

```
20.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK        17   25                108 CHANNELS
LINK        13    5                312 CHANNELS
LINK        13   22                144 CHANNELS
LINK         5   25                146 CHANNELS
LINK        22    1                288 CHANNELS
LINK        17    8                 48 CHANNELS
LINK        15    5                468 CHANNELS
LINK        27    1                408 CHANNELS


REROUTING PATHS FOR LINK    17   25
PATH    1           17   12   16   25
                       24 CHANNELS


REROUTING PATHS FOR LINK    13    5
THERE IS NO PATH BETWEEN    13 &     5.


REROUTING PATHS FOR LINK    13   22
THERE IS NO PATH BETWEEN    13 &    22.


REROUTING PATHS FOR LINK     5   25
THERE IS NO PATH BETWEEN     5 &    25.
```

(Continued on right-hand side)

```
REROUTING PATHS FOR LINK    22    1
PATH    1           22    9    1
                       24 CHANNELS


REROUTING PATHS FOR LINK    17    8
PATH    1           17   18    8
                       24 CHANNELS


REROUTING PATHS FOR LINK    15    5
PATH    1           15   20    4    5
                       24 CHANNELS


REROUTING PATHS FOR LINK    27    1
THERE IS NO PATH BETWEEN    27 &     1.


NETWORK AVAILIBILITY       .739
AVERAGE NETWORK AVAILIBILITY       .835
```

Figure 4-32. CMANA Display of Summarized ANA Analysis Results - Last Replication of 20% Damage Case for Germany Microwave LOS System

```
50.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK           5    2               72 CHANNELS
LINK          15    8              312 CHANNELS
LINK           8   17               48 CHANNELS
LINK          11   12               72 CHANNELS
LINK           5   10              360 CHANNELS
LINK           7   16               48 CHANNELS
LINK          23    7               48 CHANNELS
LINK          28   21               96 CHANNELS
LINK           1    9              120 CHANNELS
LINK           1   20              288 CHANNELS
LINK           5   24               48 CHANNELS
LINK          15   21              312 CHANNELS
LINK           2   24               48 CHANNELS
LINK          15   28              192 CHANNELS
LINK          16   25               48 CHANNELS
LINK           1   21              312 CHANNELS
LINK           1   22              288 CHANNELS
LINK          12   17              144 CHANNELS
LINK          13    1              144 CHANNELS
LINK          22   13              144 CHANNELS
LINK          12   16               96 CHANNELS
LINK           3   20              144 CHANNELS


REROUTING PATHS FOR LINK      5    2
THERE IS NO PATH BETWEEN      5 &      2.


REROUTING PATHS FOR LINK     15    8
THERE IS NO PATH BETWEEN     15 &      8.
```

(Continued on Right-Hand Side)

```
REROUTING PATHS FOR LINK      8   17
PATH    1               8   18   17
                         24 CHANNELS


REROUTING PATHS FOR LINK     11   12
THERE IS NO PATH BETWEEN     11 &     12.


REROUTING PATHS FOR LINK      5   10
THERE IS NO PATH BETWEEN      5 &     10.


REROUTING PATHS FOR LINK      7   16
THERE IS NO PATH BETWEEN      7 &     16.


REROUTING PATHS FOR LINK     23    7
THERE IS NO PATH BETWEEN     23 &      7.


REROUTING PATHS FOR LINK     28   21
THERE IS NO PATH BETWEEN     28 &     21.


REROUTING PATHS FOR LINK      1    9
THERE IS NO PATH BETWEEN      1 &      9.
```

(Continued on Next Page)

Figure 4-33. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Germany Microwave LOS System

```
REROUTING PATHS FOR LINK     1   20
THERE IS NO PATH BETWEEN     1 &    20.

REROUTING PATHS FOR LINK     5   24
THERE IS NO PATH BETWEEN     5 &    24.

REROUTING PATHS FOR LINK    15   21
THERE IS NO PATH BETWEEN    15 &    21.

REROUTING PATHS FOR LINK     2   24
THERE IS NO PATH BETWEEN     2 &    24.

REROUTING PATHS FOR LINK    15   28
THERE IS NO PATH BETWEEN    15 &    28.

REROUTING PATHS FOR LINK    16   25
THERE IS NO PATH BETWEEN    16 &    25.

REROUTING PATHS FOR LINK     1   21
THERE IS NO PATH BETWEEN     1 &    21.

REROUTING PATHS FOR LINK     1   22
THERE IS NO PATH BETWEEN     1 &    22.
```

(Continued on Right-Hand Side)

```
REROUTING PATHS FOR LINK    12   17
THERE IS NO PATH BETWEEN    12 &    17.

REROUTING PATHS FOR LINK    13    1
THERE IS NO PATH BETWEEN    13 &     1.

REROUTING PATHS FOR LINK    22   13
THERE IS NO PATH BETWEEN    22 &    13.

REROUTING PATHS FOR LINK    12   16
THERE IS NO PATH BETWEEN    12 &    16.

REROUTING PATHS FOR LINK     3   20
THERE IS NO PATH BETWEEN     3 &    20.

NETWORK AVAILIBILITY       .519
AVERAGE NETWORK AVAILIBILITY       .510
```

Figure 4-33. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Germany Microwave LOS System

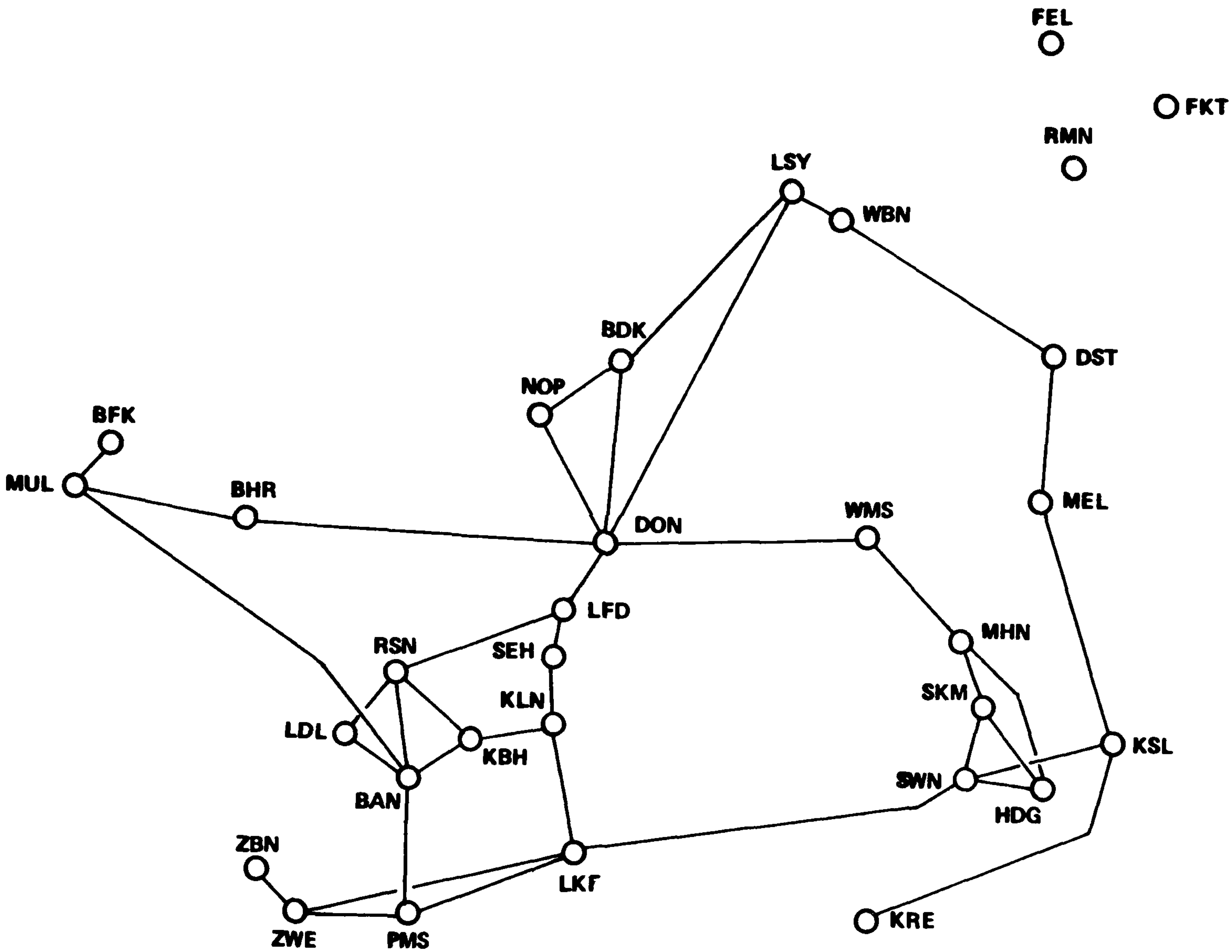

Figure 4-34. Central Germany Millimeter LOS System Network Topology

XXXXXXXXXX NETWORK XXXXXXXXXX

LINK NO.	END POINTS		LINK TRAFFIC (VOICE CH)	SPARE CHANNEL	ASSUMED LTA
1	1	9	120	24	.999
2	1	13	144	24	.999
3	1	20	504	120	.999
4	1	21	312	72	.999
5	1	22	288	72	.999
6	2	5	120	24	.999
7	2	23	48	24	.999
8	2	24	48	0	.999
9	3	20	144	24	.999
10	4	5	216	48	.999
11	4	20	780	204	.999
12	5	14	792	204	.999
13	5	24	48	0	.999
14	5	25	336	72	.999
15	6	7	48	0	.999
16	6	16	120	24	.999
17	7	23	48	0	.999
18	8	17	24	0	.999
19	8	18	480	120	.999
20	8	26	288	72	.999
21	9	10	504	132	.999
22	9	22	120	24	.999
23	10	15	204	104	.999
24	10	27	492	120	.999
25	11	12	72	24	.999
26	12	16	144	24	.999
27	12	26	264	60	.999
28	13	22	456	108	.999
29	14	22	600	156	.999
30	14	27	528	120	.999
31	15	21	264	60	.999
32	15	26	240	48	.999
33	15	28	120	24	.999
34	17	18	480	120	.999
35	17	25	336	84	.999
36	18	26	336	96	.999
37	19	28	96	24	.999
38	21	28	96	24	.999

(Continued on right-hand side)

Figure 4-35. Germany Millimeter Wave LOS System Network Input Data Displayed by CMANA

Table 4-5. ANA Analysis Results of Germany Millimeter Wave LOS System

Total Number of Nodes	28		
Total Number of Links	38		
Total Network Link Traffic (TNLT) (Voice Channels)	10260		
Total Network Spare Capacity (TNSC) (Voice Channels)	2552		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	4	8	19
Average Total Network Traffic Disruption Rate (ANTDR)	0.087	0.180	0.510
Average Total Re-routed Link Traffic Rate (ARLTR)	0.012	0.014	0.006
Average Total Network Reduction Rate (ANTRR)	0.075	0.165	0.504
Average Network Availability (ANA)	0.925	0.835	0.496

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          26   18                    336 CHANNELS
LINK           5   25                    336 CHANNELS
LINK           3   20                    144 CHANNELS
LINK          24    5                     48 CHANNELS

TOTAL                                    864 CHANNELS


REROUTING PATHS FOR LINK    26   18
PATH    1            26    8   18
                       72 CHANNELS


REROUTING PATHS FOR LINK     5   25
THERE IS NO PATH BETWEEN     5 &    25.
```

(Continued on right-hand side)

```
REROUTING PATHS FOR LINK     3   20
THERE IS NO PATH BETWEEN     3 &    20.


REROUTING PATHS FOR LINK    24    5
THERE IS NO PATH BETWEEN    24 &     5.


TOTAL REROUTED LINKS                     72 CHANNELS


NETWORK AVAILIBILITY       .923
AVERAGE NETWORK AVAILIBILITY       .925
```

Figure 4-36. CMANA Display of Summarized ANA Analysis Results - Last Replication of 10% Damage Case for Germany Millimeter Wave LOS System

```
20.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          25   17               336 CHANNELS
LINK          13   22               456 CHANNELS
LINK          12   26               264 CHANNELS
LINK          13    1               144 CHANNELS
LINK           6    7                48 CHANNELS
LINK          22    1               288 CHANNELS
LINK          16   12               144 CHANNELS
LINK          14   22               600 CHANNELS

TOTAL                              2280 CHANNELS


REROUTING PATHS FOR LINK    25   17
THERE IS NO PATH BETWEEN    25 &    17.


REROUTING PATHS FOR LINK    13   22
THERE IS NO PATH BETWEEN    13 &    22.


REROUTING PATHS FOR LINK    12   26
THERE IS NO PATH BETWEEN    12 &    26.


REROUTING PATHS FOR LINK    13    1
```

(Continued on right-hand side)

```
THERE IS NO PATH BETWEEN    13 &     1.


REROUTING PATHS FOR LINK     6    7
THERE IS NO PATH BETWEEN     6 &     7.


REROUTING PATHS FOR LINK    22    1
PATH    1           22    9    1
                      24 CHANNELS


REROUTING PATHS FOR LINK    16   12
THERE IS NO PATH BETWEEN    16 &    12.


REROUTING PATHS FOR LINK    14   22
THERE IS NO PATH BETWEEN    14 &    22.


TOTAL REROUTED LINKS                 24 CHANNELS


NETWORK AVAILIBILITY        .780
AVERAGE NETWORK AVAILIBILITY      .835
```

Figure 4-37. CMANA Display of Summarized ANA Analysis Results - Last Replication of 20% Damage Case for Germany Millimeter Wave LOS System

```
50.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          22    1              288 CHANNELS
LINK          14   27              528 CHANNELS
LINK          15   10              204 CHANNELS
LINK          27   10              492 CHANNELS
LINK          26   12              264 CHANNELS
LINK          21   28               96 CHANNELS
LINK           9    1              120 CHANNELS
LINK          22   14              600 CHANNELS
LINK          23    7               48 CHANNELS
LINK           9   22              120 CHANNELS
LINK          22   13              456 CHANNELS
LINK          13    1              144 CHANNELS
LINK          15   26              240 CHANNELS
LINK          24    5               48 CHANNELS
LINK           8   18              480 CHANNELS
LINK          20    3              144 CHANNELS
LINK           1   20              504 CHANNELS
LINK           5   14              792 CHANNELS
LINK           2    5              120 CHANNELS


REROUTING PATHS FOR LINK    22    1
THERE IS NO PATH BETWEEN    22 &     1.


REROUTING PATHS FOR LINK    14   27
THERE IS NO PATH BETWEEN    14 &    27.
```

(Continued on Right-Hand Side)

```
REROUTING PATHS FOR LINK    15   10
THERE IS NO PATH BETWEEN    15 &    10.


REROUTING PATHS FOR LINK    27   10
THERE IS NO PATH BETWEEN    27 &    10.


REROUTING PATHS FOR LINK    26   12
THERE IS NO PATH BETWEEN    26 &    12.


REROUTING PATHS FOR LINK    21   28
PATH     1              21    15    28
                          24 CHANNELS


REROUTING PATHS FOR LINK     9    1
THERE IS NO PATH BETWEEN     9 &     1.


REROUTING PATHS FOR LINK    22   14
THERE IS NO PATH BETWEEN    22 &    14.


REROUTING PATHS FOR LINK    23    7
THERE IS NO PATH BETWEEN    23 &     7.
```

(Continued on Next Page)

Figure 4-38. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Germany Millimeter Wave LOS System

```
REROUTING PATHS FOR LINK      9   22
THERE IS NO PATH BETWEEN      9 &     22.


REROUTING PATHS FOR LINK     22   13
THERE IS NO PATH BETWEEN     22 &     13.


REROUTING PATHS FOR LINK     13    1
THERE IS NO PATH BETWEEN     13 &      1.


REROUTING PATHS FOR LINK     15   26
THERE IS NO PATH BETWEEN     15 &     26.


REROUTING PATHS FOR LINK     24    5
THERE IS NO PATH BETWEEN     24 &      5.


REROUTING PATHS FOR LINK      8   18
PATH    1              8   26   18
                     72 CHANNELS


REROUTING PATHS FOR LINK     20    3
THERE IS NO PATH BETWEEN     20 &      3.
```

(Continued on Right-Hand Side)

```
REROUTING PATHS FOR LINK      1   20
THERE IS NO PATH BETWEEN      1 &     20.


REROUTING PATHS FOR LINK      5   14
THERE IS NO PATH BETWEEN      5 &     14.


REROUTING PATHS FOR LINK      2    5
THERE IS NO PATH BETWEEN      2 &      5.


NETWORK AVAILIBILITY       .455
AVERAGE NETWORK AVAILIBILITY       .496
```

Figure 4-38. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Germany Millimeter Wave LOS System (Continued)

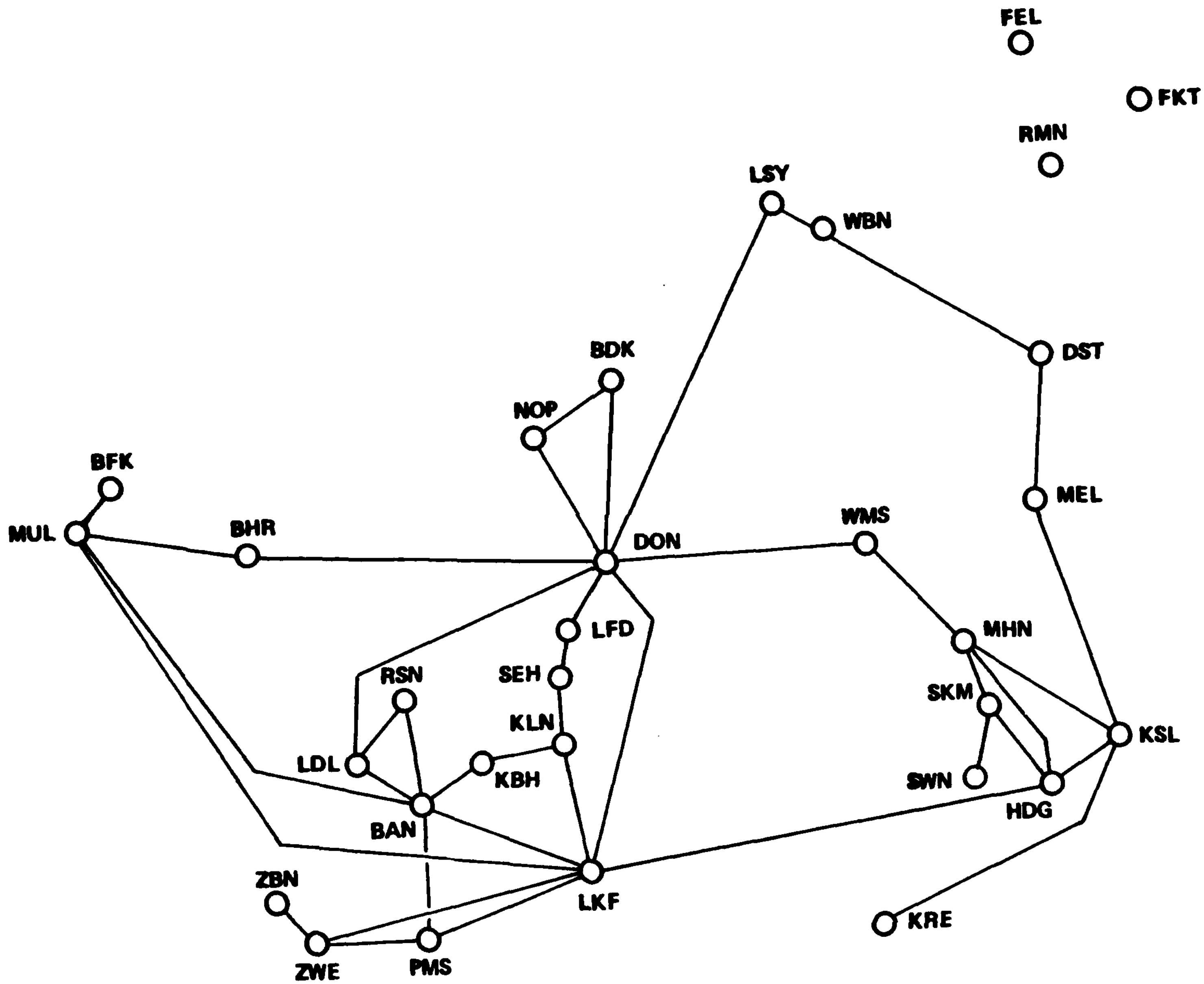

Figure 4-39. Germany Microwave and Millimeter Wave Mix System I Network Topology

Upon entry into the program, subroutine DATA is called to read in the input data file. A call to subroutine DAMAGE deletes links from the network using a random number generator. Subroutine PATH is called to search for all the re-routing paths for each deleted link. The re-routed link traffic in terms of voice channels for each deleted link is then computed using subroutine NETAVIL. Finally, the network availability and the average network availability for the disrupted network are computed. The average network availability ANA is then compared with its values for a previous replication. The process stops if the value of the difference between the ANA's is less than 5% in the last five successive comparisons, or if the total number of replications exceeds 100.

The network information, all the rerouting paths for each deleted link, and the computed ANA along with some intermediate results such as the removed links with their voice channels and the available re-routing paths for each link are written into three output files.

The flow chart of the program REROUTE is shown in Figure 4-49.

4.5.2 Subroutine DATA

Subroutine DATA reads in network data from data file 1. The network data includes the total number of nodes, the total number of links, pointers to all starting nodes of the links, array of ending nodes of the links, network capacity (link traffic and spare capacity) in terms of voice channels, link time availability for each link, and the network disruption percentage. The network data are then written into output file 2 in a format which is easy to read.

4.5.3 Subroutine DAMAGE

Subroutine DAMAGE deletes links from the network using a uniform random number generator. The total number of links to be removed is obtained from the round off product of the total number of links in the network and the network disruption percentage. All the deleted links are written into output file 3.

XXXXXXXXXX NETWORK XXXXXXXXXX

LINK NO.	END POINTS	LINK TRAFFIC (VOICE CH)	SPARE CHANNEL	ASSUMED LTA
1	1 9	120	24	.999
2	1 13	144	24	.999
3	1 20	504	120	.999
4	1 21	312	72	.999
5	1 22	288	72	.999
6	2 5	48	24	.999
7	2 24	48	0	.999
8	3 20	144	24	.999
9	4 5	216	48	.999
10	4 20	168	48	.999
11	5 13	312	72	.999
12	5 14	312	72	.999
13	5 15	202	50	.999
14	5 23	48	24	.999
15	5 24	48	0	.999
16	5 25	84	22	.999
17	6 7	48	0	.999
18	6 16	96	24	.999
19	7 23	48	0	.999
20	8 12	144	24	.999
21	8 15	48	0	.999
22	8 17	120	24	.999
23	8 18	336	96	.999
24	8 26	288	72	.999
25	9 10	312	72	.999
26	9 22	120	24	.999
27	10 27	504	108	.999
28	11 12	72	24	.999
29	12 16	144	24	.999
30	12 17	144	24	.999
31	13 22	144	48	.999
32	14 27	336	72	.999
33	15 20	216	48	.999
34	15 21	260	64	.999
35	15 28	120	24	.999
36	17 18	376	96	.999
37	17 25	348	72	.999
38	18 26	376	96	.999
39	19 28	96	24	.999
40	21 28	12	0	.999

(Continued on right-hand side)

Figure 4-40. Germany Microwave and Millimeter Wave Mix I System Network Input Data Displayed by CMANA

Table 4-6. ANA Analysis Results of Germany Microwave and Millimeter Wave Mix I System

Total Number of Nodes	28		
Total Number of Links	40		
Total Network Link Traffic (TNLT) (Voice Channels)	7706		
Total Network Spare Capacity (TNSC) (Voice Channels)	1756		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	4	8	20
Average Total Network Traffic Disruption Rate (ANTDR)	0.090	0.177	0.483
Average Total Re-routed Link Traffic Rate (ARLTR)	0.016	0.024	0.013
Average Total Network Reduction Rate (ANTRR)	0.075	0.153	0.470
Average Network Availability (ANA)	0.925	0.847	0.530

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          15    5                   202 CHANNELS
LINK           1    9                   120 CHANNELS
LINK           8   17                   120 CHANNELS
LINK          20   15                   216 CHANNELS


REROUTING PATHS FOR LINK     15    5
THERE IS NO PATH BETWEEN     15 &      5.


REROUTING PATHS FOR LINK      1    9
PATH    1             1   22    9
                       24 CHANNELS
PATH    2             1   13    5   14   27   10    9
                       24 CHANNELS
PATH    3             1   20    4    5   14   27   10    9
                       48 CHANNELS


REROUTING PATHS FOR LINK      8   17
PATH    1             8   12   17
                       24 CHANNELS
PATH    2             8   18   17
                       96 CHANNELS
```

(Continued on right-hand side)

```
REROUTING PATHS FOR LINK    20   15

PATH    1             20    1   21   15
                         64 CHANNELS


NETWORK AVAILIBILITY        .951
AVERAGE NETWORK AVAILIBILITY        .925
```

Figure 4-41. CMANA Display of Summarized ANA Analysis Results - Last Replication of 10% Damage Case for Germany Microwave and Millimeter Wave Mix I System

```
20.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          12   17                  144 CHANNELS
LINK          17    8                  120 CHANNELS
LINK          12   11                   72 CHANNELS
LINK          12   16                  144 CHANNELS
LINK           5   25                   84 CHANNELS
LINK          20   15                  216 CHANNELS
LINK          15   28                  120 CHANNELS
LINK          13    5                  312 CHANNELS


REROUTING PATHS FOR LINK     12   17
THERE IS NO PATH BETWEEN     12 &    17.


REROUTING PATHS FOR LINK     17    8
PATH    1             17   18    8
                         96 CHANNELS


REROUTING PATHS FOR LINK     12   11
THERE IS NO PATH BETWEEN     12 &    11.


REROUTING PATHS FOR LINK     12   16
THERE IS NO PATH BETWEEN     12 &    16.
```

(Continued on right-hand side)

```
REROUTING PATHS FOR LINK     5   25
THERE IS NO PATH BETWEEN     5 &    25.


REROUTING PATHS FOR LINK     20   15
PATH    1             20    4    5   15
                        48 CHANNELS
PATH    2             20    1   21   15
                        64 CHANNELS


REROUTING PATHS FOR LINK     15   28
THERE IS NO PATH BETWEEN     15 &    28.


REROUTING PATHS FOR LINK     13    5
PATH    1             13    1    9   10   27   14    5
                        24 CHANNELS
PATH    2             13   22    9   10   27   14    5
                        24 CHANNELS


NETWORK AVAILIBILITY          .876
AVERAGE NETWORK AVAILIBILITY          .847
```

Figure 4-42. CMANA Display of Summarized ANA Analysis Results - Last Replication of 20% Damage Case for Germany Microwave and Millimeter Wave Mix I System

```
50.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK        24   2           48 CHANNELS
LINK         4  20          168 CHANNELS
LINK         1  22          288 CHANNELS
LINK        20  15          216 CHANNELS
LINK        25  17          348 CHANNELS
LINK        13  22          144 CHANNELS
LINK        14   5          312 CHANNELS
LINK        27  10          504 CHANNELS
LINK         8  17          120 CHANNELS
LINK        21  28           12 CHANNELS
LINK        25   5           84 CHANNELS
LINK        22   9          120 CHANNELS
LINK         9   1          120 CHANNELS
LINK        12  16          144 CHANNELS
LINK        15   5          202 CHANNELS
LINK        23   7           48 CHANNELS
LINK         8  26          288 CHANNELS
LINK         8  12          144 CHANNELS
LINK        18  26          376 CHANNELS
LINK         1  20          504 CHANNELS

TOTAL                      4190 CHANNELS


REROUTING PATHS FOR LINK    24   2
THERE IS NO PATH BETWEEN    24 &   2.
```

(Continued on right-hand side)

```
REROUTING PATHS FOR LINK     4  20
THERE IS NO PATH BETWEEN     4 &  20.

REROUTING PATHS FOR LINK     1  22
THERE IS NO PATH BETWEEN     1 &  22.

REROUTING PATHS FOR LINK    20  15
THERE IS NO PATH BETWEEN    20 &  15.

REROUTING PATHS FOR LINK    25  17
THERE IS NO PATH BETWEEN    25 &  17.

REROUTING PATHS FOR LINK    13  22
THERE IS NO PATH BETWEEN    13 &  22.

REROUTING PATHS FOR LINK    14   5
THERE IS NO PATH BETWEEN    14 &   5.

REROUTING PATHS FOR LINK    27  10
THERE IS NO PATH BETWEEN    27 &  10.
```

(Continued on next page)

Figure 4-43. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Germany Microwave and Millimeter Wave Mix I System

```
REROUTING PATHS FOR LINK      8   17
PATH    1              8   18   17
                          96 CHANNELS


REROUTING PATHS FOR LINK     21   28

PATH    1             21   15   28
                          12 CHANNELS


REROUTING PATHS FOR LINK     25    5
THERE IS NO PATH BETWEEN     25 &      5.


REROUTING PATHS FOR LINK     22    9
THERE IS NO PATH BETWEEN     22 &      9.


REROUTING PATHS FOR LINK      9    1
THERE IS NO PATH BETWEEN      9 &      1.


REROUTING PATHS FOR LINK     12   16
THERE IS NO PATH BETWEEN     12 &     16.
```

(Continued on right-hand side)

```
REROUTING PATHS FOR LINK     15    5
PATH    1              15   21    1   13    5
                          24 CHANNELS


REROUTING PATHS FOR LINK     23    7
THERE IS NO PATH BETWEEN     23 &      7.


REROUTING PATHS FOR LINK      8   26
THERE IS NO PATH BETWEEN      8 &     26.


REROUTING PATHS FOR LINK      8   12

THERE IS NO PATH BETWEEN      8 &     12.


REROUTING PATHS FOR LINK     18   26
THERE IS NO PATH BETWEEN     18 &     26.


REROUTING PATHS FOR LINK      1   20
THERE IS NO PATH BETWEEN      1 &     20.

NETWORK AVAILIBILITY          .473
AVERAGE NETWORK AVAILIBILITY          .530
```

Figure 4- 43. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Germany Microwave and Millimeter Wave Mix I System (Continued)

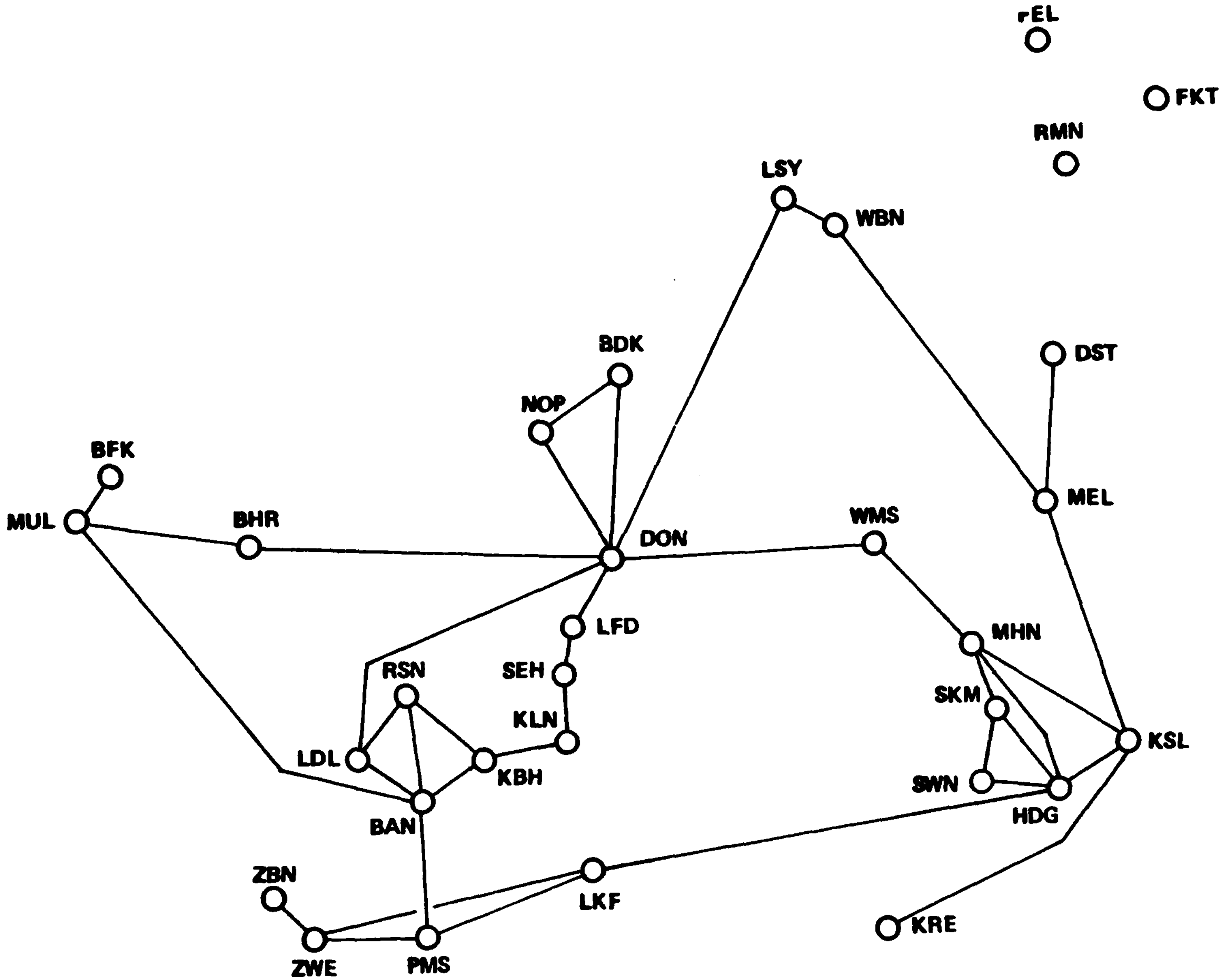

Figure 4-44. Germany Microwave and Millimeter Wave Mix System II Network Topology

XXXXXXXXXX NETWORK XXXXXXXXXX

LINK NO.	END POINTS		LINK TRAFFIC (VOICE CH)	SPARE CHANNEL	ASSUMED LTA
1	1	9	336	72	.999
2	1	13	144	24	.999
3	1	20	504	120	.999
4	1	21	312	72	.999
5	1	22	288	72	.999
6	2	5	48	24	.999
7	2	24	48	0	.999
8	3	20	144	24	.999
9	4	5	216	48	.999
10	4	20	168	48	.999
11	5	13	312	72	.999
12	5	14	504	120	.999
13	5	23	48	24	.999
14	5	24	48	0	.999
15	5	25	336	72	.999
16	6	16	48	24	.999
17	7	16	48	0	.999
18	7	23	48	0	.999
19	8	12	144	24	.999
20	8	15	48	0	.999
21	8	17	120	24	.999
22	8	18	336	96	.999
23	8	26	288	72	.999
24	9	10	932	128	.999
25	9	22	120	24	.999
26	10	15	408	96	.999
27	10	27	682	170	.999
28	11	12	72	24	.999
29	12	16	144	24	.999
30	12	17	144	24	.999
31	13	22	144	48	.999
32	14	27	528	120	.999
33	15	21	264	60	.999
34	15	28	120	24	.999
35	17	18	336	96	.999
36	17	25	336	84	.999
37	18	26	336	96	.999
38	19	28	96	24	.999
39	21	28	96	24	.999

(Continued on right-hand side)

Figure 4-45. Germany Microwave and Millimeter Wave Mix II System Network Input Data Displayed by CMANA

Table 4-7. ANA Analysis Results of Germany Microwave and Millimeter Wave Mix II System

Total Number of Nodes	28		
Total Number of Links	39		
Total Network Link Traffic (TNLT) (Voice Channels)	9294		
Total Network Spare Capacity (TNSC) (Voice Channels)	1978		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	3	7	19
Average Total Network Traffic Disruption Rate (ANTDR)	0.073	0.154	0.495
Average Total Re-routed Link Traffic Rate (ARLTR)	0.063	0.021	0.007
Average Total Network Reduction Rate (ANTRR)	0.010	0.133	0.489
Average Network Availability (ANA)	0.931	0.866	0.505

```
10.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          15   28                    120 CHANNELS
LINK           2   24                     48 CHANNELS
LINK           8   12                    144 CHANNELS


REROUTING PATHS FOR LINK     15   28
PATH    1            15   21   28
                       24 CHANNELS


REROUTING PATHS FOR LINK      2   24
THERE IS NO PATH BETWEEN      2 &    24.


REROUTING PATHS FOR LINK      8   12
PATH    1             8   17   12
                       24 CHANNELS


NETWORK AVAILIBILITY        .972
AVERAGE NETWORK AVAILIBILITY       .931
```

Figure 4-46. CMANA Display of Summarized ANA Analysis Results - Last Replication of 10% Damage Case for Germany Microwave and Millimeter Mix II System

```
20.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK          10   15                408 CHANNELS
LINK          24    2                 48 CHANNELS
LINK          26    8                288 CHANNELS
LINK          16    6                 48 CHANNELS
LINK           5   24                 48 CHANNELS
LINK          12   17                144 CHANNELS
LINK          16   12                144 CHANNELS


REROUTING PATHS FOR LINK    10   15
PATH    1          10    9    1   21   15
                    60 CHANNELS
PATH    2          10    9    1   21   28   15
                    12 CHANNELS


REROUTING PATHS FOR LINK    24    2
THERE IS NO PATH BETWEEN    24 &     2.


REROUTING PATHS FOR LINK    26    8
PATH    1          26   18    8
                    96 CHANNELS


REROUTING PATHS FOR LINK    16    6
THERE IS NO PATH BETWEEN    16 &     6.
```
(Continued on right-hand side)

```
REROUTING PATHS FOR LINK     5   24
THERE IS NO PATH BETWEEN     5 &    24.


REROUTING PATHS FOR LINK    12   17
PATH    1             12    8   17
                      24 CHANNELS


REROUTING PATHS FOR LINK    16   12
THERE IS NO PATH BETWEEN    16 &    12.


NETWORK AVAILIBILITY       .899
AVERAGE NETWORK AVAILIBILITY       .866
```

Figure 4-47. CMANA Display of Summarized ANA Results - Last Replication of 20% Damage Case for Germany Microwave and Millimeter Wave Mix II System

```
50.00 % OF LINKS REMOVED

REMOVED LINKS AND THEIR VOICE CHANNELS ARE :
LINK         17   12               144 CHANNELS
LINK         13   22               144 CHANNELS
LINK         24    5                48 CHANNELS
LINK         10    9               932 CHANNELS
LINK         20    4               168 CHANNELS
LINK         24    2                48 CHANNELS
LINK          1   22               288 CHANNELS
LINK         25   17               336 CHANNELS
LINK         14    5               504 CHANNELS
LINK         27   10               682 CHANNELS
LINK         20    3               144 CHANNELS
LINK          8   26               288 CHANNELS
LINK         21   28                96 CHANNELS
LINK         12   16               144 CHANNELS
LINK         15    8                48 CHANNELS
LINK         23    7                48 CHANNELS
LINK          9    1               336 CHANNELS
LINK         18   17               336 CHANNELS
LINK          1   20               504 CHANNELS


REROUTING PATHS FOR LINK    17   12
PATH    1            17    8   12
                        24 CHANNELS


REROUTING PATHS FOR LINK    13   22
THERE IS NO PATH BETWEEN    13 &    22.
```

(Continued on Right-Hand Side)

```
REROUTING PATHS FOR LINK    24    5
THERE IS NO PATH BETWEEN    24 &     5.


REROUTING PATHS FOR LINK    10    9
THERE IS NO PATH BETWEEN    10 &     9.


REROUTING PATHS FOR LINK    20    4
THERE IS NO PATH BETWEEN    20 &     4.


REROUTING PATHS FOR LINK    24    2
THERE IS NO PATH BETWEEN    24 &     2.


REROUTING PATHS FOR LINK     1   22
THERE IS NO PATH BETWEEN     1 &    22.


REROUTING PATHS FOR LINK    25   17
THERE IS NO PATH BETWEEN    25 &    17.


REROUTING PATHS FOR LINK    14    5
THERE IS NO PATH BETWEEN    14 &     5.
```

(Continued on Next Page)

Figure 4-48. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Germany Microwave and Millimeter Wave Mix II System

```
REROUTING PATHS FOR LINK     27   10
THERE IS NO PATH BETWEEN     27 &     10.


REROUTING PATHS FOR LINK     20    3
THERE IS NO PATH BETWEEN     20 &      3.


REROUTING PATHS FOR LINK      8   26
PATH     1              8   18   26
                         96 CHANNELS


REROUTING PATHS FOR LINK     21   28
PATH     1             21   15   28
                         24 CHANNELS


REROUTING PATHS FOR LINK     12   16
THERE IS NO PATH BETWEEN     12 &     16.


REROUTING PATHS FOR LINK     15    8
THERE IS NO PATH BETWEEN     15 &      8.


REROUTING PATHS FOR LINK     23    7
THERE IS NO PATH BETWEEN     23 &      7.
```

(Continued on Right-Hand Side)

```
REROUTING PATHS FOR LINK      9    1
THERE IS NO PATH BETWEEN      9 &      1.


REROUTING PATHS FOR LINK     18   17
THERE IS NO PATH BETWEEN     18 &     17.


REROUTING PATHS FOR LINK      1   20
THERE IS NO PATH BETWEEN      1 &     20.


NETWORK AVAILIBILITY        .452
AVERAGE NETWORK AVAILIBILITY        .505
```

Figure 4-48. CMANA Display of Summarized ANA Analysis Results - Last Replication of 50% Damage Case for Germany Microwave and Millimeter Wave Mix II System (Continued)

4.5.4 Subroutine PATH

Subroutine PATH searches for the rerouting paths for a deleted link. The tree structure is used to store data for the re-routed paths. Each branch of the tree represents a single path between the root of the tree (one node of a disrupted link) and the leaf of the tree (the other node of the disrupted link). The total number of branches of the tree gives the total number of searched re-routing paths. Besides, the linked-list data structure is used for more flexibility.

For a given disrupted link, all the re-routing paths are searched and arranged in an ascending order of length, i.e., the number of relays of the path. The results are written into output file 4.

4.5.5 Subroutine NETAVIL

NETAVIL computes the re-routed link traffic in voice channels, if any, for all the disrupted links. All the paths for re-routing all the disrupted links obtained from subroutine PATH are arranged in ascending order of length before NETAVIL being called. NETAVIL checks all the links in a re-routing path to see if any spare capacity is available to re-route the traffic for the corresponding deleted link. If yes, the minimum of the number of spare channels for all the links in the path will be the number of re-routed channels for the path. This process proceeds from the shortest to the longest path until all the paths have been checked or all the disrupted links have been re-routed. The re-routing paths for each disrupted link are written into output file 3. A message is written into output file 3 if no re-routing path is available for a disrupted link.

4.6 IMPROVED ALTERNATIVE SYSTEMS AND THEIR ANAs

The average network availability of each alternative, computed and shown in Sections 4.3 and 4.4, can be further improved. The ways of improving the ANA have also been discussed already, namely,

- o Providing more spare capacity for each link to facilitate re-routing traffic of disrupted links
- o Adding more redundant links to the network and to form more loops to provide more alternative paths.

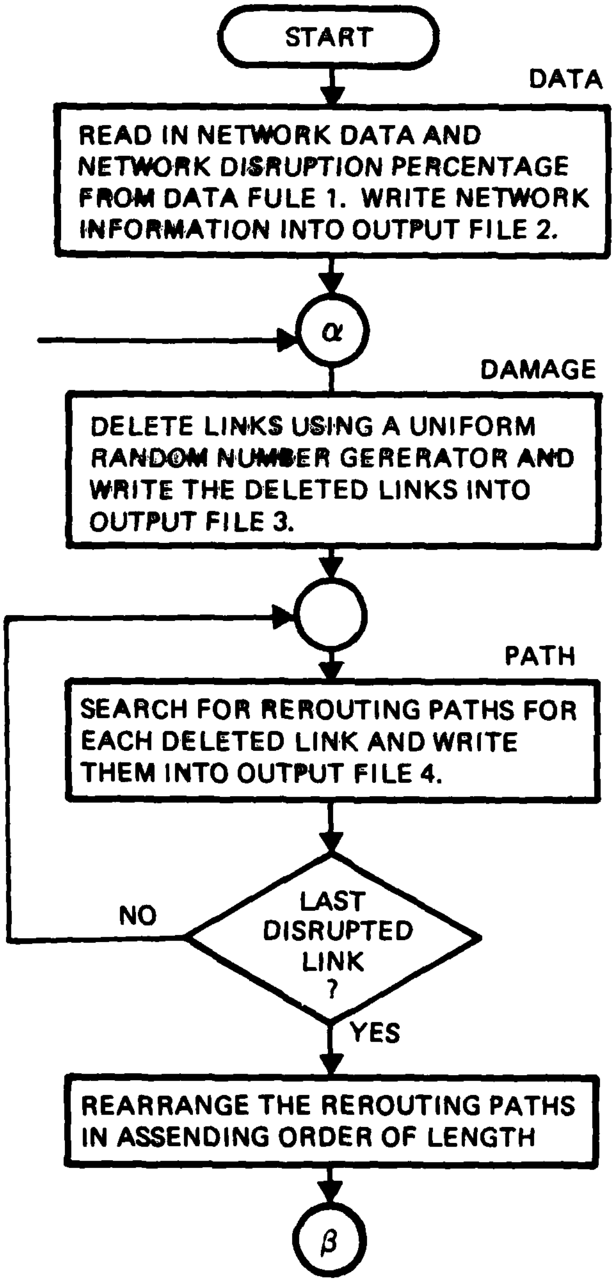

Figure 4-49. Flow Chart of CMANA Program (Sheet 1)

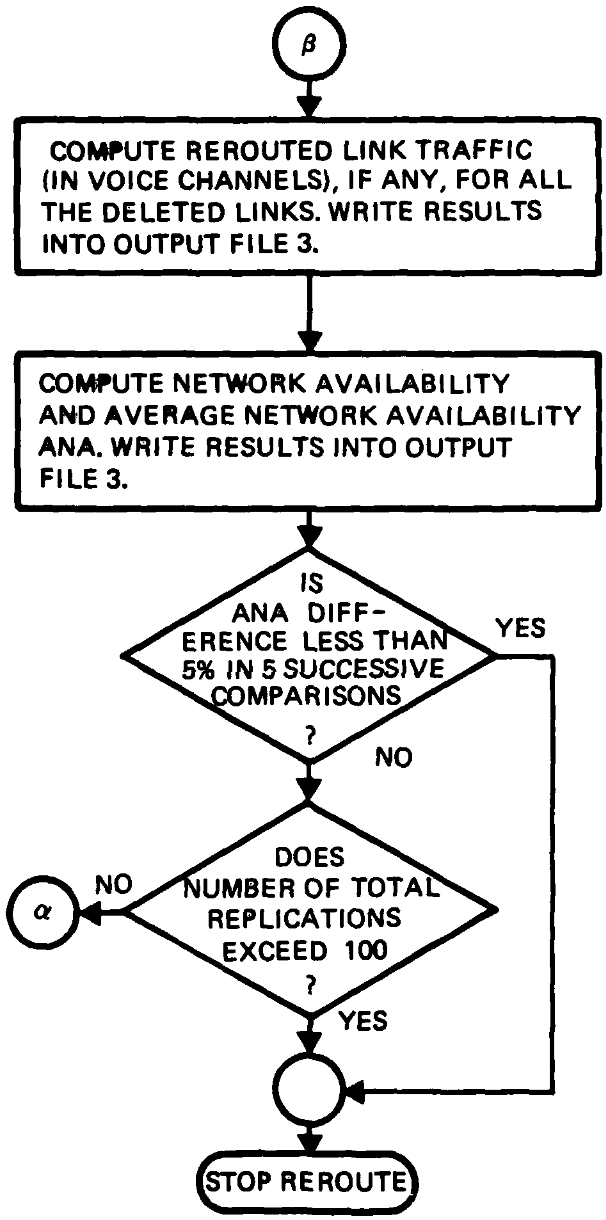

Figure 4-49. Flow Chart of CMANA Program (Sheet 2)

To exercise the developed CMANA program and to verify the above two concepts, these proposed alternatives have been modified. The resulted systems are called improved systems. The links and capacities of each improved system are shown in Tables 4-8 to 4-13 inclusive. The CMANA is then applied to each of the improved alternative systems. The average network availability of each system is displayed in Tables 4-14 to 4-19 respectively. For comparison, the ANA of the corresponding proposed network is included in these tables. In general, a higher ANA is obtained for each improved system. Improved networks should not be considered as recommended alternatives. In other words, these improved alternatives are not properly engineered. The added redundant links and increased spare capacities for all links are done more or less based on intuition. Nevertheless, all improved network do provide higher ANA.

Table 4-8. Improved LOS Network for Oahu, Hawaii

No.	Link	Capacity (T1)
1	MTK-WHW	6/2
2	LLL-SFD	6/2
3	SFD-WHW	12.5/11.5
4	WHW-WLR	19/5
5	KUN-WLR	12.5/3.5
6	WLR-SFD	8/8
7	KUN-HKM	8/2
8	BBP-FDL	12.5/3.5
9	PLH-CPS	6/10
10	CPS-MKL	12.5/11.5
11	PLH-MKL	19/5
12	FTS-MKL	12.5/3.5
13	MKL-HKM	6/10
14	WHW-PLH	19/5
15	FDL-PLH	6/10
16	PLH-HKM	19/5
17	WHW-FDL	12.5/11.5
18	WHW-CPS	6/10
19	KUN-SFD	0/8
20	WLR-HKM	0/8
21	MTK-SFD	0/8
22	LLL-KUN	0/8
23	BBP-PLH	0/8
24	FTS-HKM	0/8

Table 4-9. Improved Fiber Optic Network for Oahu, Hawaii

No.	Link	Capacity (T1)
1	MTK-WHW	6/2
2	SFD-WHW	12.5/11.5
3	WHW-WLR	25.5/6.5
4	SFD-KUN	12.5/3.5
5	SFD-LLL	6/2
6	BBP-X01	12.5/10
7	KUN-X01	6/11.5
8	WLR-X02	6/10
9	X02-MKL	6/10
10	CPS-MKL	25.5/11.5
11	FTS-MKL	12.5/11.5
12	MKL-PLH	19/5
13	MKL-HKM	12.5/11.5
14	HKM-PLH	19/13
15	X02-FDL	19/5
16	X01-X02	19/13
17	WHW-PLH	19/13
18	WHW-CPS	12.5/11.5
19	SFD-WLR	12.5/3.5
20	LLL-BBP	0/8
21	CPS-FTS	0/8
22	MTK-SFD	0/8
23	FDL-PLH	0/8
24	KUN-WLR	0/8

Table 4-10. Improved Microwave LOS Network for Central Germany

No.	Link	Capacity (T1)	No.	Link	Capacity (T1)
1	BAN-KBH	5/7	25	HDG-SKM	5/7
2	BAN-LDL	5.5/6.5	26	HDG-SWN	12.5/3.5
3	BAN-MUL	12.5/3.5	27	KBH-RSN	5/8
4	BAN-LKF	0/8	28	KBH-LKF	9/7
5	BAN-PMS	13/9	29	KBH-MUL	9/7
6	BAN-RSN	12.5/3.5	30	KLN-LKF	18.5/8.5
7	BAN-SEH	13/9	31	KLN-SEH	16.5/7.5
8	BDK-DON	2.5/1.5	32	KRE-KSL	3/1
9	BDK-NOP	0/2	33	KSL-MEL	4/4
10	BFK-BHR	0/4	34	KSL-MHN	5.5/2.5
11	BFK-MUL	5.5/2.5	35	KSL-SWN	5.5/2.5
12	BHR-DON	9/7	36	LDL-MUL	0/8
13	BHR-MUL	7.5/4.5	37	LDL-RSN	6.5/9.5
14	DON-KLN	23/9	38	LFD-SEH	1/.5
15	DON-LDL	13/9	39	LKF-PMS	11/5
16	DON-LSY	2.5/2.5	40	LKF-ZWE	5/3
17	DON-NOP	1.5/2.5	41	LSY-WBN	0/2
18	DON-SEH	8.5/7.5	42	MEL-WMS	0/4
19	DON-WMS	4/4	43	MHN-SKM	5/7
20	DST-FKT	0/4	44	MHN-WMS	4.5/3.5
21	DST-MEL	4/4	45	PMS-ZWE	0/5
22	DST-WBN	1.5/2.5	46	SKM-SWN	5/7
23	FKT-LSY	0/4	47	ZBN-ZWE	4/1
24	HDG-LKF	10/6			

Table 4-11. Improved Millimeter Wave LOS Network for Central Germany

No.	Link	Capacity (T1)	No.	Link	Capacity (T1)
1	BAN-KBH	18/10	24	KBH-KLN	22/10
2	BAN-LDL	20/10	25	KBH-RSN	14/10
3	BAN-PMS	13/11	26	KLN-LKF	17.5/10.5
4	BAN-RSN	12.5/11.5	27	KLN-SEH	26.5/5.5
5	BDK-DON	5/7	28	KRE-KSL	3/1
6	BDK-LSY	2.5/5.5	29	KSL-MEL	4/8
7	BDK-NOP	0/8	30	KSL-SWN	5.5/8.5
8	BFK-BHR	0/4	31	LDL-MUL	21.5/10.5
9	BFK-MUL	5.5/2.5	32	LDL-NOP	0/8
10	BHR-DON	9/7	33	LDL-RSN	28.5/7.5
11	BHR-LDL	0/6	34	LFD-RSN	13/11
12	BHR-MUL	7.5/4.5	35	LFD-SEH	1/7
13	DON-LFD	13/9	36	LKF-PMS	11/9
14	DON-NOP	1.5/6.5	37	LKF-SWN	0/8
15	DON-SEH	18.5/9.5	38	LKF-ZWE	5/3
16	DON-WMS	14/10	39	LSY-WBN	0/8
17	DST-FKT	0/8	40	MEL-WMS	0/8
18	DST-MEL	4/8	41	MHN-SKM	5/7
19	DST-WBN	1.5/6.5	42	MHN-WMS	14.5/9.5
20	FKT-LSY	0/8	43	PMS-ZWE	0/5
21	HDG-MHN	10/6	44	SKM-SWN	5/9
22	HDG-SKM	5/7	45	ZBN-ZWE	4/1
23	HDG-SWN	12.5/3.5			

Table 4-12. Improved Microwave and Millimeter Wave Mix I Network for Central Germany

No.	Link	Capacity (Tl)	No.	Link	Capacity (Tl)
1	BAN-KVH	5/7	25	HDG-LKF	10/6
2	BAN-LDL	5.5/6.5	26	HDG-SKM	5/7
3	BAN-MUL	12.5/3.5	27	HDG-SWN	12.5/3.5
4	BAN-LKF	0/8	28	KBH-RSN	5/8
5	BAN-PMS	13/9	29	KBH-LKF	9/7
6	BAN-RSN	12.5/3.5	30	KBH-MUL	9/7
7	BAN-SEH	13/9	31	KLN-LKF	18.5/8.5
8	BDK-DON	2.5/1.5	32	KLN-SEH	16.5/7.5
9	BDK-NOP	0/2	33	KRE-KSL	3/1
10	BFK-BHR	0/4	34	KSL-MEL	4/4
11	BFK-MUL	5.5/2.5	35	KSL-MHN	5.5/2.5
12	BHR-DON	9/7	36	LDL-MUL	0/8
13	BHR-MUL	7.5/4.5	37	LDL-RSN	6.5/9.5
14	DON-KLN	23/9	38	LFD-SEH	1/.5
15	DON-LDL	13/9	39	LKF-PMS	11/5
16	DON-LSY	2.5/2.5	40	LKF-ZWE	5/3
17	DON-NOP	1.5/2.5	41	LSY-WBN	0/2
18	DON-SEH	8.7/7.5	42	MEL-WMS	0/4
19	DON-WMS	4/4	43	MHN-SKM	5/7
20	DST-FKT	0/4	44	MHN-WMS	4.5/3.5
21	DST-MEL	4/4	45	PMS-ZWE	0/5
22	DST-WBN	1.5/2.5	46	SKM-SWN	5/7
23	FKT-LSY	0/4	47	ZBN-ZWE	4/1
24	HDG-KSL	5.5/2.5			

Table 4-13. Improved Microwave and Millimeter Wave Mix II Network for Central Germany

No.	Link	Capacity (T1)	No.	Link	Capacity (T1)
1	BAN-KBH	18/10	24	HDG-SKM	5/7
2	BAN-LDL	20/10	25	HDG-SWN	12.5/7.5
3	BAN-PMS	13/11	26	KBH-KLN	22/10
4	BAN-RSN	12.5/11.5	27	KBH-RSN	14/10
5	BDK-DON	5/7	28	KLN-LKF	17.4/10.5
6	BDK-LSY	2.5/5.5	29	KLN-SEH	26.5/5.5
7	BDK-NOP	0/8	30	KRE-KSL	3/1
8	BFK-BHR	0/4	31	KSL-MEL	4/8
9	BFK-MUL	5.5/2.5	32	KSL-MHN	5.5/6.5
10	BHR-DON	9/7	33	LDL-MUL	21.5/10.5
11	BHR-LDL	0/6	34	LDL-NOP	0/8
12	BHR-MUL	7.5/4.5	35	LDL-RSN	15.5/8.5
13	DON-LDL	13/11	36	LFD-SEH	1/7
14	DON-LFD	0/8	37	LKF-PMS	11/9
15	DON-NOP	1.5/6.5	38	LKF-ZWE	5/3
16	DON-SEH	18.5/9.5	39	LSY-WBN	0/8
17	DON-WMS	14/10	40	MEL-WBN	1.5/6.5
18	DST-FKT	0/8	41	MEL-WMS	0/8
19	DST-MEL	4/8	42	MHN-SKM	5/7
20	FKT-LSY	0/8	43	MHN-WMS	14.5/9.5
21	HDG-KSL	5.5/2.5	44	PMS-ZWE	0/5
22	HDG-LKF	0/8	45	SKM-SWN	5/9
23	HDG-MHN	10/6	46	ZBN-ZWE	4/1

Table 4-14. ANA Analysis Results of Improved Hawaii LOS System

Total Number of Nodes	13		
Total Number of Links	24		
Total Network Link Traffic (TNLT) (Voice Channels)	4872		
Total Network Spare Capacity (TNSC) (Voice Channels)	4008		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	2	4	12
Average Total Network Traffic Disruption Rate (ANTDR)	0.086	0.196	0.412
Average Total Re-routed Link Traffic Rate (ARLTR)	0.057	0.114	0.009
Average Total Network Reduction Rate (ANTRR)	0.019	0.082	0.410
Average Network Availability (ANA)	0.989	0.904	0.589
ANA of Proposed System	0.946	0.850	0.557

Table 4-15. ANA Analysis Results of Improved Hawaii Fiber Optic System

Total Number of Nodes	15		
Total Number of Links	24		
Total Network Link Traffic (TNLT) (Voice Channels)	6324		
Total Network Spare Capacity (TNSC) (Voice Channels)	4932		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	2	5	12
Average Total Network Traffic Disruption Rate (ANTDR)	0.063	0.202	0.448
Average Total Re-routed Link Traffic Rate (ARLTR)	0.042	0.079	0.031
Average Total Network Reduction Rate (ANTRR)	0.021	0.123	0.417
Average Network Availability (ANA)	0.994	0.877	0.580
ANA of Proposed System	0.912	0.818	0.534

Table 4-16. ANA Analysis Result of Improved Germany Microwave LOS System

Total Number of Nodes	29		
Total Number of Links	47		
Total Network Link Traffic (TNLT) (Voice Channels)	6979		
Total Network Spare Capacity (TNSC) (Voice Channels)	5616		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	5	9	24
Average Total Network Traffic Disruption Rate (ANTDR)	0.062	0.123	0.544
Average Total Re-routed Link Traffic Rate (ARLTR)	0.024	0.045	0.046
Average Total Network Reduction Rate (ANTRR)	0.035	0.077	0.462
Average Network Availability (ANA)	0.963	0.919	0.537
ANA of Proposed System	0.948	0.835	0.510

Table 4-17. ANA Analysis Results of Improved Germany Millimeter LOS System

Total Number of Nodes	29		
Total Number of Links	45		
Total Network Link Traffic (TNLT) (Voice Channels)	9108		
Total Network Spare Capacity (TNSC) (Voice Channels)	7788		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	5	9	23
Average Total Network Traffic Disruption Rate (ANTDR)	0.119	0.188	0.522
Average Total Re-routed Link Traffic Rate (ARLTR)	0.057	0.624	0.040
Average Total Network Reduction Rate (ANTRR)	0.062	0.124	0.482
Average Network Availability (ANA)	0.938	0.877	0.518
ANA of Proposed System	0.925	0.835	0.496

Table 4-18. ANA Analysis Results of Improved Germany Microwave and Millimeter Wave Mix I System

Total Number of Nodes	29		
Total Number of Links	46		
Total Network Link Traffic (TNLT) (Voice Channels)	8556		
Total Network Spare Capacity (TNSC) (Voice Channels)	8184		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	5	9	23
Average Total Network Traffic Disruption Rate (ANTDR)	0.105	0.177	0.465
Average Total Re-routed Link Traffic Rate (ARLTR)	0.059	0.072	0.046
Average Total Network Reduction Rate (ANTRR)	0.046	0.105	0.419
Average Network Availability (ANA)	0.954	0.895	0.581
ANA of Proposed System	0.925	0.847	0.530

Table 4-19. ANA Results of Germany Microwave and Millimeter Wave Mix II System

Total Number of Nodes	29		
Total Number of Links	47		
Total Network Link Traffic (TNLT) (Voice Channels)	6948		
Total Network Spare Capacity (TNSC) (Voice Channels)	5688		
Network Damage Percentage	10	20	50
Number of Links Removed Randomly	5	9	24
Average Total Network Traffic Disruption Rate (ANTDR)	0.072	0.147	0.501
Average Total Re-routed Link Traffic Rate (ARLTR)	0.028	0.039	0.077
Average Total Network Reduction Rate (ANTRR)	0.043	0.185	0.423
Average Network Availability (ANA)	0.971	0.926	0.576
ANA of Proposed System	0.931	0.866	0.505

5.0 SYSTEM COST MODELS

This section presents the system cost models for the microwave LOS system, millimeter LOS system, and fiber optic system. These system cost models are then used as bases to developing a system life cycle cost for all proposed transmission alternatives.

5.1 *INTRODUCTION*

The cost model of the microwave LOS system is based upon the developed transmission model documented in Section 4.1 of Phase II Task 1 Final Report (Ref. 1-3) and the technology projection, plus preliminary costing done for microwave equipment as part of the Phase IB effort (Ref. 1-2). The format of the cost model is a modified version of the one described in Defense Communications Agency Circular Gov-60-1, Cost and Planning Factors Manual (Ref. 5-1).

The millimeter wave LOS system cost model is based on the transmission model as described in Section 4.2 of Phase II Task 1 Final Report and preliminary costing done for Hawaii millimeter wave system as given in Phase IB Final Report (Ref. 1-2). The format of the millimeter wave model follows that of the microwave system.

The costing model of a fiber optic system is also based on the transmission model developed for Phase II Task 1 effort and given in Section 4.3 of the Final Report (Ref. 1-3), and the preliminary costing done for the fiber optic system in Hawaii and Central Germany for DCS III Phase IB (Ref. 1-2). The basic format used for the microwave cost model is also adopted for fiber optics.

A brief summary of the transmission model for each medium is provided in Section 2.4 of this report for ready reference.

5.2 System Options

The equipment options of these three transmission media are listed in the following subsections.

5.2.1 Microwave LOS System Options

1. LOS microwave radio; Terminal with hot standby

   a. Frequency; 8 GHz

b. Power output; 2 watt

c. Diversity; space

2. Antenna

a. Diameter; 6 ft.

b. Polarization; plane

c. Performance; standard

5.2.2 Optical Fiber System

1. Optical Fiber Cable

a. Type; Mono mode

b. Length; 50 km

c. No. of fiber per cable; 10

2. Light Source; ILD

3. Photodetector; APD

4. Cable Installation; Duct

5.3 MATERIAL AND DEPLOYMENT COST

Once the equipment options have been selected, the estimated manufacturer's costs can be inserted. From these cost figures the acquisition costs can be derived. The acquisition costs for major equipment are derived from the addition of manufacturer's basic cost plus performance verification costs, quality control costs, source and delivery inspection costs, purchasing costs, and shipping costs. These costs will vary depending upon the complexity of the equipment. The above costs are grouped into what can be called a loading factor.

The acquisition costs for installation material are derived from a quantity factor based upon the type of equipment to be installed and a loading factor, derived from the above factors.

The acquisition costs for test equipment and spares are also derived from a quantity factor based upon the type of equipment and the acquisition costs of the major equipment.

For a fiber optic system, ducting and laying the optical cable is

an additional deployment cost item. It has been estimated at \$45/m in open country and \$55/m in urban developed areas.

5.3.1 Material Costing Methodology

Step-by-step methodology of developing cost of a system is listed below:

1. Electronics Equipment
   a. Manufacturer's Estimate
   b. Quantity Reduction Factor
   c. Basic Cost
   d. Acquisition Cost = Loading Factor x Basic Cost
2. Towers and Poles
   a. Manufacturer's Estimate
   b. Acquisition Cost = Loading Factor x Manufacturer's Estimate
3. Fiber Optic Cable
   a. Manufacturer's Estimate
   b. Basic Cost = Quantity Factor x Distance x Manufacturer's Estimate
   c. Acquisition Cost = Loading Factor x Basic Cost
4. Installation Material
   a. Basic Cost = Quantity Factor x Electronics Equipment Basic Cost
   b. Acquisition Cost = Loading Factor x Basic Cost
5. Test Equipment
   a. Acquisition Cost = Quantity Factor x Electronics Equipment Acquisition Cost
6. Spare Parts
   a. Electronics

      Basic Cost = Quantity Factor x Electronics

Equipment Basic Cost

Acquisition Cost = Loading Factor x Basic Cost

b. Installation Material Spares

Basic Cost = Quantity Factor x Installation Material Basic Cost

Acquisition Cost = Loading Factor x Basic Cost

c. Test Equipment Spares

Acquisition Cost = Test Equipment Acquisition

Cost x Quantity Factor

7. Total Acquisition Costs (Quantity Factor)

5.3.2 Acquisition Factors for Microwave and Millimeter Wave Equipment

The following acquisition factors for microwave and millimeter wave have been derived from actual costing information:

1.	Electronic Equipments; Loading Factor	= 1.7
2.	Towers & Poles; Loading Factor	= 1.4
3.	Installation Material; Quantity Factor	= 0.05
4.	Installation Material; Loading Factor	= 1.037
5.	Test Equipment; Quantity Factor	= 0.10
6.	Spare Parts Electronics; Quantity Factor	= 0.15
	Installation; Quantity Factor	= 0.05
7.	Spare Parts Test Equipment; Quantity Factor	= 0.10

5.3.3 Acquisition Factor for Fiber Optic System

The following acquisition factors for fiber optic system have been derived from actual costing information:

1.	Electronics Loading Factor	= 2.3
2.	Installation Equipment; Fiber Optic Cable Length; Quantity Factor	= 0.15
3.	Fiber Distance Factor	= 1.1

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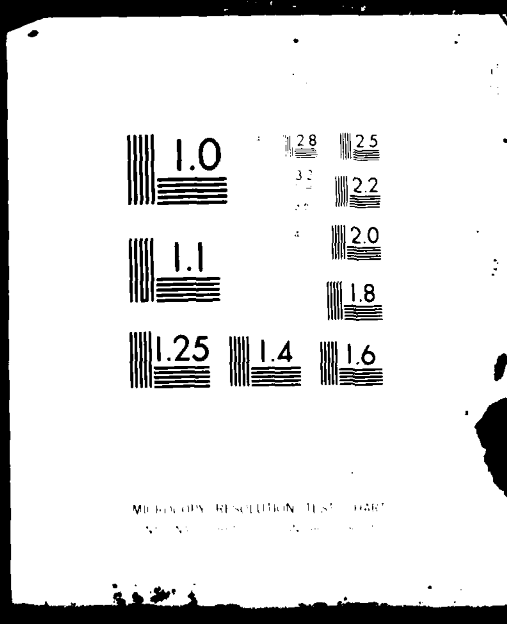

4. Fiber Optic Duct Length; Duct Distance Factor = 1.05

5. Spare Parts Electronics; Quantity Factor = 0.1

   Spare Parts, Fiber and Duct; Quantity Factor = 0.01

6. Test Equipment; Quantity Factor = 0.08

5.4 DEPLOYMENT COST

The deployment costs include all labor and associated facilitating costs necessary for the installation, test, and cutover of the system.

This costing figure consists of two factors: Engineering (about 1/3 of the cost) and Installation (about 2/3 of the cost) and test. As recommended in Chapter 15 of Reference 5-1, the deployment cost, not including test and cutover, is taken to be 20% of the Basic Material Costs. Test and cutover cost add another 10% of the Basic Material Cost.

Therefore, deployment Costs = 1.3 x Equipment Acquisition Costs.

5.5 TOTAL INITIAL COSTS

Total initial costs of a terminal/station of the three media considered are presented in this section. However a standard terminal/station is assumed, cost differential caused by variations from the standard terminal/station will be considered in the system life cycle cost.

5.5.1 Microwave LOS System Cost

The total initial cost of a standard microwave LOS terminal has been estimated as follows:

1.	Material Cost	Quantity	Total Cost ($)
a.	Radio Equipment	1	50,000
b.	Antenna (10 ft.)	1	6,000
c.	Feed System (80M, $21/m)	1	1,800
d.	Dehydrator	1	1,400
e.	Orderwire Equipment	1	2,500
f.	Alarm and Control	1	1,500
g.	Primary and Auxiliary Power Plant	1	10,000
h.	Tower	1	40,000

2. Acquisition Costs	Total Cost ($ K)
Electronics	
$(a+b+c+d+e+f+g) \times 1.7 = A_T$	124
Towers	
$h \times 1.4 = B_T$	56
Installation Material	
$0.05 \times (a+b+c+d+e+f+g) \times 1.037 = C_T$	6
Test Equipment	
$0.10 \times A_T = D_T$	12
Total Acquisition Costs	
$= A_T + B_T + C_T + D_T$	198

3. Initial Cost

Total Initial Cost = 2.3 (Acquisition Cost) 455

5.5.2 Millimeter Wave LOS System Cost

The total initial cost of a millimeter wave LOS terminal has been estimated as follows:

1. Material Cost	Quantity	Total Cost ($K)
a. MM-Wave Terminal Radio	1	65
b. Primary & Auxiliary Power	1	8
c. Antenna Tower (30m)	1	

2. Acquisition Costs	Total Cost ($K)
Electronics	
$a \times 1.7 = A_T$	110
Mount	
$b \times 1.4 = B_T$	56
Installation Material	
$0.05 \times a \times 1.037 = C_T$	6

Test Equipment

$0.10 \times A = D_T$ 11

Total Acquisition Cost

$= A_T + B_T + C_T + D_T$ 183

3. Initial Cost

Total Initial Cost

= 2.3 (Acquisition Cost) 425

5.5.3 Fiber Optic System Cost

The total initial cost of a standard fiber optic system has been estimated and tabulated as follows. However, a span of 50 km, the maximum distance without repeater, is assumed. For system with distance other than the one assumed here, the cost can be easily adjusted accordingly.

1. Material Cost	Quantity	Total Cost
a. Electro-Optic Tx/Rx Terminal	2	68,400
b. Connectors	12	2,400
c. Optical Fiber	50km	25,000
d. Duct and Hardware ($2.18/km)	5km	10,915

2. Acquisition Costs	Total Cost ($ K)
Electronics	
$(a+b) \times 2.3 = A_T$	162
Optical Fiber	
$c \times 1.1 \times 2.3 = B_T$	63
Duct and Hardware	
$d \times 1.05 \times 2.3 = C_T$	26
Installation Equipment	
$C_T \times 0.15 = D_T$	4
Spares	
$(A_T) \times 0.1 + (B_T+C_T) \times 0.01 = E_T$	17

Test Equipment

$(A_T+B_T) \times 0.08 = F_T$ 18

Total Acquisition Costs

$A_T+B_T+C_T+D_T+E_T+F_T$ 290

3. Initial Cost

Total Initial Cost 1,540

The total initial cost of a fiber optic system is estimated as the total acquisition cost plus $25/M of over deployment cost.

5.6 OPERATING AND MAINTENANCE COST

The annual cost of operating and maintenance of the proposed transmission alternatives is presented and discussed in this Section. Note that a centralized operating and maintenance policy has been adopted. One Network Maintenance and Control Center (NMC) is proposed to take care of about twenty terminals/sites. The total cost of a NMC is then distributed to each terminal/site.

5.6.1 Personnel

It is assumed that no sites will be manned for either microwave, mm-wave or fiber optic systems. There will be a central alarm and control point from where information on the status of all equipment will be monitored (Network Maintenance Control Center (NMC)). It is further assumed that one operations person can handle a microwave, millimeter wave, or fiber optic terminal and NMC with twenty sites reporting. This is because field maintenance will become much simpler in the year 2000 than it is today. For instance, fault isolation via the Network Maintenance Control Center will be down to the card level; also, with built in test equipment replacement check out will be quick and relatively simple.

It is assumed that 0.075 man-year of manpower is required for maintenance per site per year. The salary of technical maintenance personnel has been taken as $20,000 per year and 60 percent of benefit and overall administrative overhead expenses, annual operation and maintenance personnel cost per site is $2,400.

5.6.2 Transportation

To cover an area consisting of about 20 terminals/sites, a vehicle is assigned to a NMC for site visits and repairs. The initial cost of the vehicle is assumed to be $9,000 and the operating life is 10 years. It is assumed the average mileage of the maintenance vehicle is $9,000 miles per year and vehicle operating cost is $0.18 per mile. Therefore,

Initial Cost Per Annum	$ 9,000/10 = $	900
Operating Cost Per Annum	$0.18x9000 =	1,620
Total Cost Per Annum	$ 2,562	

Hence, the annual vehicle cost per site is $128.00

5.6.3 Material Cost

The material costs considered are system spare consumption and test equipment maintenance. The former is taken to be half of the initial spare and the latter one tenth of test equipment acquisition cost.

5.7 ANNUAL OPERATING COST

The annual operating costs for the three transmission media have been estimated according to the previous sections and are given below:

1. Microwave Terminal

Initial Cost	455,000
Spares Consumption	.5 x (0.15 x 124,000) + 0.1 x (12,400)
	= 10,540
Operating Cost	O&M + Spares Consumption
	128 + 2400 + 10,540
	= 13,068

2. Millimeter Wave Terminal

Initial Cost	183,000
Spares Consumption	.5 x (0.15 x 183,000) + 0.1 x (18,300)
	= 15,550
Operating Cost	128 + 2,400 + 15,550
	= 18,078

3. Fiber Optic System

In this case the link and two terminals are considered.

Initial Cost	290,000
Spares Consumption	0.5 x (17,000) + .1 x (18,000)
	= 10,300
Operating Cost	O&M + Spares Consumption
	= (128 + 2400) x 2 + 10,300
	= 15,356

6.0 LIFE CYCLE COST OF ALTERNATIVE SYSTEM

This section presents the results of costing of various alternative transmission systems as described in Sections 6 and 7 of Phase II Task 1 Final Report, Evaluation of DCS III Transmission Alternatives. The system design, i.e., link topology and capacity of alternative designs has been modified somewhat in the process of system performance evaluation and costing. The proposed alternative systems, as summarized in Section 2.4.2 of this report, are the base of the costs estimated in this section.

The estimated costs are presented in the following sections and grouped according to the areas of interest. However, considerations and discussions of each alternative transmission system from the viewpoint of system cost is presented along with the system life cycle cost.

6.1 COST METHODOLOGY

The estimated life cycle for each of the candidate transmission systems includes initial deployment costs and projected recurring operations and maintenance expenditures. Costs, which are summarized together with assumptions and restrictions, are presented for each of the areas of concern. All costs are projected to the year 2000, in 1980 dollars. Cost reduction due to either advancement or maturing of developing technologies has been forecasted and included in cost estimation.

6.1.1 Cost Elements

The cost of each proposed alternative transmission system includes the following cost elements:

1. Acquisition and deployment cost
2. Marginal cost for expansion of existing common support facilities
3. System engineering and project management cost
4. System test and evaluation cost
5. Training cost

6. Spares consumption

7. Test equipment operating and maintenance

8. Personnel cost

9. Vehicle cost.

The first five cost elements constitute the initial system cost, and the last four cost elements the annual system sustaining cost.

6.1.2 <u>Cost Projection</u>

The "1980 dollars cost" of the year 2000 system reflects the cost for the system based on advancement of developing technologies assumed to be available in the year 2000, i.e., as though the technologies of the year 2000 were available today.

Projection of the year 2000 cost in 1980 dollars has been made based on a weighted composite of cost factors between the year 1980 to 1990, forecasted by Data Resourcess Incorporation of non-home construction wage rates based on data supplied by Bureau of Economics Analysis, Department of Commerce. No detailed projected costs of labor or produce beyond the year 1990 is currently available. Lacking such projection, simple extrapoloation of the same rate increases, as projected for 1980-1990, is used for the year 1991-2000. Using this cost projection, the projected annual rate of increase for the year 1980 through the year 2000 is 7.3 percent per annum, corresponding to a multiplicative factor of 2.09 for that period. However, this average annual rate increase should be revised whenever a new, reliable long-range prediction is available.

Labor costs are assumed to increase by the same factor as discussed above for material and spare parts.

The ten year life cycle cost is not factored by the present value of future value considerations. It is simply total initial cost plus ten times total annual sustaining cost.

6.1.3 Assumptions and Ground Rules of Costing

In Assembly cost estimates, in addition to the project cost increase as discussed in Section 6.1.2, some assumptions and ground rules have been consistently applied. These are:

1. Cost estimates are only made for RF transmission media. Multiplexing and demultiplexing equipments are not included, hence, switching equipments are also excluded in the cost estimates presented in the section.

2. The multiplexing format of currently available and developing equipments such as AN/FCC-98 and AN/FCC-99 is assumed. A third level multiplexing format is also proposed (See Section 2.4.1). The bit rates of interfaces for insertion, drop, or baseband equipment are either of Level 1 rate (1.544 Mbps), Level 2 rates (3.252, 6.464, 9.696, or 12. 928 Mbps) or Level 3 rates (multiples of 12.928 Mbps).

3. Acquisition cost include materials, initial spares, and supporing test equipment. It is assumed that all equipments and documentation are produced to best commercial standards.

4. Deployment costs include all labor and associated facilitating costs necessary for the installation of the systems. These costs do not include acquisition of land, rights-of-ways, etc.

5. Marginal cost is the cost for expansion of existing common support facilities which are assumed to be already in place for supporting current or previous communications facilities.

6. System engineering and project management includes cost of developing program plan, system engineering, project management, acquiring and shipping the system components and material, and preparation system level documentation.

7. Test and evaluation cost includes system test and performance evaluation. The cost of cut-over of the system is also included.

8. Training cost is based on two week training of a small number (a dozen) maintenance personnel of the system.

9. Sustaining costs consists of four elements: Spare consumption--replenishment of initial system spares, test equipment--calibration and maintenance cost of test equipment plus their spares replenishment, personnel--labor cost necessary to maintain the system to specified operation standard, and vehicle--cost for operating a test equipment, spares, and tool equipped vehicle to facilitate the maintenance of non-attendant sites.

10. It is further assumed that operation and maintenance would be integrated into the existing support structure of the DCS.

6.2 LIFE CYCLE COSTS OF HAWAII ALTERNATIVE SYSTEMS

Three alternative transmission systems are designed for Oahu Island, Hawaii. They are microwave LOS system, millimeter wave LOS system, and fiber optic system. The detailed design information of these systems is given in Section 6 of Phase II Task 1 Final Report, Evaluation of DCS III Transmission Alternatives. These systems have been modified slightly during the Task 2 performance period. The proposed systems as given in Section 2.4.3 of this report are the systems cost in this section. Using the system cost model as described in Section 5, the life cycle cost of these systems are predicted and tabulated in Tables 6-1, 6-2, and 6-3 respectively. Detailed supporting cost data are given in Annex A.

It should be pointed out that both the microwave LOS system and the fiber optic system are designed to fulfill the 0.99 ETE requirement, but the millimeter wave LOS system is designed to fulfill the 0.90 ETE requirement. As shown in Section 3.2 the number of repeaters required for a millimeter LOS system with 0.90, 0.95, and 0.99 are 11, 32, and 49 respectively; implementation of an 0.99 ETE system requires unreasonably high life cycle cost which is not recommended. Note that the ETE availability predication is made on the basis of individual links. Since the proposed system is already provided with three redundant links and

Table 6-1. Life Cycle Cost of Microwave LOS System for Oahu, Hawaii

COST ITEM	COST ($K)
Initial Cost	
Acquisition	$ 6,564K
Deployment	1,969
Marginal Cost	33
System Engineering and Project Management	450
System Test and Evaluation	590
Training Cost	34
TOTAL INITIAL COST	$ 9,640K
Sustaining Cost (Annual)	
Spare Consumption	338
Test Equipment Operating and Maintenance	45
Personnel Cost	38
Vehicle Cost	2
TOTAL SUSTAINING COST (ANNUAL)	$ 423K
TEN YEAR LIFE CYCLE COST	$13,870K

Table 6-2. Life Cycle Cost of Millimeter Wave LOS System for Oahu, Hawaii

COST ITEM	COST ($K)
Initial Cost	
Acquisition	10,813
Deployment	3,244
Marginal Cost	54
System Engineering and Project Management	762
System Test and Evaluation	973
Training Cost	34
TOTAL INITIAL COST	15,880
Sustaining Cost (Annual)	
Spare Consumption	571
Test Equipment Operating and Maintenance	76
Personnel Cost	62
Vehicle Cost	3
TOTAL SUSTAINING COST (ANNUAL)	712
TEN YEAR LIFE CYCLE COST	23,000

Table 6-3. Life Cycle Cost of Fiber Optic System for Oahu, Hawaii

COST ITEM	COST ($K)
Initial Cost	
Acquisition	$ 7,305K
Deployment	5,678
Marginal Cost	37
System Engineering and Project Management	350
System Test and Evaluation	510
Training Cost	34
TOTAL INITIAL COST	$13,914K
Sustaining Cost (Annual)	
Spare Consumption	186
Test Equipment Operating and Maintenance	50
Personnel Cost	36
Vehicle Cost	2
TOTAL SUSTAINING COST (ANNUAL)	$ 274K
TEN YEAR LIFE CYCLE COST	$16,654K

a high percentage of spare channels for most links, the actual ETE availability will definitely be higher than 0.90 due to the re-routing capability of path diversity built into the system. It is felt that ETE availability of 0.95 or higher is achievable. However, an accurate ETE figure cannot be provided at this time due to the lack of information of path diversity of the millimeter wave LOS system. It is because neither detailed temporal and spatial rainfall statistics nor operating experience of the path diversity system are available.

6.3 LIFE CYCLE COSTS OF GERMANY ALTERNATIVE SYSTEMS

In Central Germany, four alternative transmission systems are proposed and designed. These systems are microwave LOS system, millimeter wave LOS system, and microwave and millimeter wave mix system I and II. Details of these system designs are documented in Section 7 of Phase II Task 1 Final Report, Evaluation of DCS III Transmission Alternatives. These systems have been revised slightly during the performance evaluation and cost estimate Task 2 period. The cost estimates are based on the proposed systems as summarized in Section 2.4.3 of this report.

The life cycle cost of each system is estimated using the system cost model presented in Section 5. Tables 6-4 to 6-7 inclusive tabulated the major cost elements of each system. Some detailed cost information is provided in Annex A.

The microwave LOS system consists of 29 terminals and 4 repeaters. All links are designed for ETE availability of 0.99. The millimeter LOS system consists of 28 terminals and 51 repeaters; each link is designed for ETE availability of 0.90. The number of repeaters needed for 0.95 and 0.99 ETE availability is 82 and 156 respectively. These higher ETE availability systems are considered too costly, hence, not recommended. As remarks made for the Hawaii millimeter wave system, the actual achievable ETE may be higher than the design goal because of the available redundant links and spare capacity provided for all links. As for the microwave and millimeter wave mix system I, there are 28 terminals and three microwave repeaters. Millimeter wave links are only employed for short spans, and there is no millimeter wave repeater. From the ETE

Table 6-4. Life Cycle Cost of Microwave LOS System of Central Germany

COST ITEM	COST ($K)
Initial Cost	
Acquisition	$14,853K
Deployment	4,456
Marginal Cost	74
System Engineering and Project Management	1,009
System Test and Evaluation	1,337
Training Cost	34
TOTAL INITIAL COST	$21,763K
Sustaining Cost (Annual)	
Spare Consumption	757
Test Equipment Operating and Maintenance	101
Personnel Cost	79
Vehicle Cost	4
TOTAL SUSTAINING COST (ANNUAL)	$ 941K
TEN YEAR LIFE CYCLE COST	$31,173K

Table 6-5. Life Cycle Cost of Millimeter Wave LOS System of Central Germany

COST ITEM	COST ($K)
Initial Cost	
Acquisition	$29,283K
Deployment	8,785
Marginal Cost	146
System Engineering and Project Management	2,072
System Test and Evaluation	2,636
Training Cost	34
TOTAL INITIAL COST	$42,956K
Sustaining Cost (Annual)	
Spare Consumption	1,554
Test Equipment Operating and Maintenance	207
Personnel Cost	190
Vehicle Cost	10
TOTAL SUSTAINING COST (ANNUAL)	$ 1,961K
TEN YEAR LIFE CYCLE COST	$62,566K

Table 6-6. Life Cycle Cost of Microwave and Millimeter Wave Mix I for Central Germany

COST ITEM	COST ($K)
Initial Cost	
Acquisition	$13,738K
Deployment	4,121
Marginal Cost	69
System Engineering and Project Management	939
System Test and Evaluation	1,237
Training Cost	48
TOTAL INITIAL COST	$20,152K
Sustaining Cost (Annual)	
Spare Consumption	705
Test Equipment Operating and Maintenance	94
Personnel Cost	74
Vehicle Cost	4
TOTAL SUSTAINING COST (ANNUAL)	$ 877K
TEN YEAR LIFE CYCLE COST	$28,922K

Table 6-7. Life Cycle Cost of Microwave and Millimeter Wave Mix II for Central Germany

COST ITEM	COST ($K)
Initial Cost	
Acquisition	$18,338K
Deployment	5,510
Marginal Cost	92
System Engineering and Project Management	1,275
System Test and Evaluation	1,650
Training Cost	48
TOTAL INITIAL COST	$26,913K
Sustaining Cost (Annual)	
Spare Consumption	956
Test Equipment Operating and Maintenance	127
Personnel Cost	108
Vehicle Cost	6
TOTAL SUSTAINING COST (ANNUAL)	$ 1,197K
TEN YEAR LIFE CYCLE COST	$38,883K

availability point of view, this is a mixed system, all microwave links are with 0.99 ETE availability and all millimeter wave links with 0.90 ETE availability. The overall ETE availability of this system certainly is higher than 0.95 and approaching 0.99 because of the small number of millimeter wave links, about a dozen, and re-routing capability provided by the microwave links which are not subject to rainfall fadeout. The second mixed system, termed microwave and millimeter wave mix system II consists of 28 terminals and 17 repeaters. In contrast with the mix I system, the mix II system utilizes millimeter wave links not only for short span but also for its wideband capability. Usually, two alternative path are provided for critical links, one microwave and one millimeter wave. As mentioned already, microwave and millimeter wave links are designed based on 0.99 and 0.95 ETE availability respectively. However, the overall link availability is about 0.95.

6.4 SUMMARY OF ALTERNATIVE SYSTEMS COST

The life cycle cost of the proposed seven alternative systems are summarized in Table 6-8 for comparison.

Table 6-8. Summary of Alternative System Cost

ALTERNATIVE SYSTEM	TOTAL INITIAL COST	TOTAL SUSTAINING COST	TEN YEAR LIFE CYCLE COST
Microwave LOS System, Oahu, Hawaii	8,533	423	13,869
Millimeter LOS System, Oahu, Hawaii	14,058	713	23,000
Fiber Optic System, Oahu, Hawaii	13,914	274	16,654
Microwave LOS System, Central Germany	19,309	941	31,171
Millimeter Wave LOS System, Central Germany	38,069	1,961	62,567
Microwave and Millimeter Wave Mix I, Central Germany	17,860	877	28,920
Microwave and Millimeter Wave Mix II, Central Germany	26,904	1,197	38,874

7.0 SUMMARY, COMPARISON, AND RECOMMENDATIONS

This section first presents a brief summary of the Phase II Task 2 effort of the DCS III Study. Then a high level comparison is made for the various proposed alternative systems. Finally, recommendations are given in the last section.

7.1 SUMMARY OF PHASE II TASK 2 EFFORT

This report presents the results of the Phase II Task 2 effort of "Evaluation of DCS III Transmission Alternatives" Program. The major effort for this task is network performance evaluation and life-cycle cost estimation.

In the Phase II Task 1 performance period, three and four alternative networks are designed for Oahu Island, Hawaii and Central Germany respectively. These alternatives are:

1. Oahu Island, Hawaii
   - Microwave LOS System
   - Millimeter Wave LOS System
   - Fiber Optic System
2. Central Germany
   - Microwave LOS System
   - Millimeter Wave LOS System
   - Microwave and Millimeter Mix System I
   - Microwave and Millimeter Mix System II

These systems have been re-examined and slightly modified. Two options are prepared for each system; one is the minimum system and the other is the proposed system. The minimum system barely fulfills the traffic requirement. The proposed system which is a modified minimum system can provide better survivability. These systems are shown in Section 2.4.3.

The performance of the proposed system has been evaluated for both the benign environment and specified stressed conditions. The evaluation and results for benign environment have been presented in Section 3. The criteria of evaluation is to meet the bit error rate requirement and the prorated availability allocation.

The measure used for network performance under a stressed condition is "Average Network Availability". The methodology of Average Network Availability is defined, developed, and described in Sections 4.1, 4.2 and 4.5. The results of evaluation are presented in Sections 4.3 and 4.4.

To facilitate predication of life-cycle cost for each alternative, a system cost model has been formulated for each transmission medium; microwave, millimeter wave and fiber optics. The cost model includes material cost, deployment cost, and operating and maintenance cost. These cost models are provided in Section 5. The Life-cycle cost estimate expressed in terms of 1980 dollars for each proposed alternative system is presented in Section 6.

Following this brief summary, a comparison of system performance in terms of ANA and cost is given in the next Subsection 7.2 and recommendations for the follow-on work are provided in Subsection 7.3.

7.2 ALTERNATIVE NETWORK COMPARISON

Three alternative transmission systems are designed and evaluated along with the cost for Hawaii. Four alternative transmission systems are designed and evaluated along with the cost for Germany. This section provides comparison of these networks in tabular form.

Table 7-1. Comparison of Hawaii System
Alternative Transmission System

	Performance Under Stressed Condition (ANA)			Life-Cycle Cost
	10% Damage	20% Damage	50% Damage	($ K)
Microwave LOS System	0.946	0.850	0.557	13,868
Millimeter Wave LOS System	0.946	0.850	0.557	22,703
Fiber Optic System	0.912	0.818	0.534	16,652

Table 7-2. Comparison of Central Germany
Alternative Transmission System

	Performance Under Stressed Condition (ANA)			Life-Cycle Cost
	10% Damage	20% Damage	50% Damage	($ K)
Microwave LOS System	0.914	0.782	0.510	31,170
Millimeter Wave LOS System	0.921	0.859	0.496	62,567
Microwave and Millimeter Wave Mix I	0.918	0.839	0.476	28,920
Microwave and Millimeter Wave Mix II	0.925	0.866	0.505	38,873

7.3 RECOMMENDATIONS

Recommendations on follow-on research and development programs regarding transmission media, system design, network planning and survivability are presented in this subsection. These recommendations are identified during the performance period of Phase II effort of the DCS III program, therefore, the scope of these recommendations is restricted by the area considered and media investigated, and does not necessarily cover the whole spectrum of DCS.

7.3.1 Third Level Multiplexers and Demultiplexers

During the RF system model development and network planning and design periods, it was found that a third level multiplexer and demultiplexer is needed to define signal format, information bit rate, mission bit rate, modulation format and transmission bandwidth. This is due to the fact that traffic of many proposed links are much higher than the maximum information bit of 12.352 Mbps of the military standard second level multiplexer FCC-99. To facilitate the link and network design for the current work, a third level multiplexer/demultiplexer is proposed which could accommodate four or more FCC-99 and one FCC-98 with six 64 kbps channels for service/control/alarm. This results in a total mission transmission bit rate of 52.096 Mbps. The other alternative is the assumption that a modulator or a transmitter can accept up to four FCC-99 12.928 Mbps mission streams plus a service/control/alarm bit stream up to 384 kbps.

Development of a military third level multiplexer/demultiplexer is recommended. Apparently, this third level multiplexer/demultiplexer design should be based on the current standard of first level and second level multiplexers, namely FCC-98 and FCC-99. The maximum number of FCC-99 ports to be provided should be determined. The strip-down format of the third level multiplexer also needs to be formulated. It is anticipated that high speed and high quality fax, color television, and computer data exchange would be a few examples of future communication needed. Therefore, the third level multiplexer should be able to accommodate mission bit streams for these services.

7.3.2 Millimeter Wave Radio

There are currently many millimeter wave research and development activities, however, emphasis is placed on components and devices. Most current on-going programs are either satellite communications oriented or for short range tactical use. It was found, during the RF system model development and cost estimation, that there isn't any digital millimeter radio in production.

Consequently, it is recommended that a development program of wideband digital radio should be initiated and sponsored by a government agency. This millimeter wave radio should not be merely a microwave radio scaled downward in size or scaled upward in frequency. Some millimeter wave unique features and system issues should be dealt with in this program.

The following are a few examples.

1. Solar powered and pole mounted repeater. The millimeter LOS radio spacing is relatively short (See Section 3.2), and fortunately, power, size, and weight of a millimeter wave repeater are also small. A pole mounted or building top installed repeater with solar power supply and supplemented with a battery should be developed for non-attendant operation.

2. Adaptive close-loop carrier level control. For 0.99 ETE availability, 65 db rainfall margin should be provided for a 3.5 km millimeter wave link in Central Germany and 81 dB for a 3 km link in Hawaii. (See Table 3.3-6 and 3.3-1). The peak transmitter power (2 w) is needed only for a small fraction of time. For fine weather, most of the transmitter power is not only wasted but also causes interference. Therefore a close-loop carrier level adaptive control should be developed to automatically set the transmitter power level for providing a satisfactory signal to noise ratio at the receiving end. This control will facilitate the solar powered repeater development because of the reduction of demand on power supply capacity.

3. Atmospheric Effect on Millimeter Wave. The design of millimeter wave link encountered a difficulty or uncertainty that the rain attenuation has to be treated probabilistically. Furthermore, detailed information of rain cell size, rain rate, temporal and spatial distribution are not available. The statistical rain data of weather records are limited to long term, yearly, monthly, and/or daily rainfall rate at specified locations. Temporal data, for example maximum rain rate, average minute rain rate, and rain rate variation along a line or in a small area, needed for accurate link design is not available. Consequently, a research program of atmospheric effects on millimeter wave propagation is recommended. This program should consist, at least, of the following efforts.

- Collect statistical data of rainfall parameters
- Experimentally observe rain effect on terrestrial and satellite links
- Conduct theoretic analysis and develop computer simulation of rain effects on millimeter wave propagation
- Correlate theoretic results and experimental observations to validate theoretic analysis and simulation model
- Experimentally and theoretically investigate path diversity technique.

7.3.4 Fiber Optics

Fiber optics have been rapidly developing worldwide by commercial enterprises and some foreign governments. Some commercial systems have been field tested and large scale installations have been planned. It appears that no government initiated or sponsored program is needed, however, both U. S. Army and Navy are working in tactical and long haul fiber optic communications.

Nevertheless, the recently and rapidly advanced integrated optics and optical switching technologies need attention. These technologies could very well lead to a fiber optic network with various kinds of relay, re-route, and switching centers located underground, non-attendant. Careful monitoring of the progress of these technologies and sponsoring of needed development programs should be initiated.

7.3.5 Survivable Communications Network Design Concept

A large portion of current project effort has been placed on the network survivability. This effort includes, definition of measure of network survivability, survivability evaluation methodology, computer model development and test, and evaluation of the survivability of proposed networks. However, the network survivability or the Average Network Availability (See Sections 4.3, 4.4, and 4.6) of various networks is not completely satisfactory. Using the ANA methodology, it is seen that with x-percent of network damage, the ANA is a little better than or different from (100-X) percent. This difference results from re-routing traffic of damaged links through spare channels of surviving links. Therefore, improved network survivability or ANA can be obtained by the following two means:

1. Increase the spare capacity of links, to provide more capability to re-routing traffic of disrupted links.
2. Add more spare links to form local or global loops. The traffic could be distributed among all available links, i.e., all spare links also share some traffic.

To have a highly survivable network with nearly perfect ANA, i.e. ANA approaching 100 percent, a very large number of spare links are needed, and spare capacity of each link of a loop should be large enough to carry re-route traffic of any one link of the loop. This may result in a network with very high initial and life-cycle cost.

A different approach or concept of survivable communication network worthwhile studying is the one with the following features:

1. The network is of a mesh structure, a schematic is depicted in Figure 7-1.

2. The communications centers and users should not be colocated with the nodes of mesh but connected to a few nearby nodes through independent links as shown in Figure 7-1.

3. Each node is provided with certain switching and re-routing capability.

4. The mesh network supports both common user and dedicated user traffic.

5. The mesh network also provides analog and digital communications services.

6. Message switching may be used for data and digitized analog communications. For high rate, bulk data and computer data exchange, packet switching may be employed.

This survivable network concept should be developed, and investigated. Network design principle and procedure should be formulated. A requirement of network survivability and/or circuit survivability also needs to be defined. Then this new concept can be evaluated and compared with a network developed according to the current practice.

7.3.6 Network Survivability Computer Simulation Program

The Computer Model of Average Network Availability developed for the current project has demonstrated its capability and usefulness. However, the following program refinement and enhancement is recommended.

The current available CMANA can be further refined in the following aspects:

1. Optimize the required core storage space. A large core space is required for tracing all possible re-routing paths for each damaged link. The current program works fine, however, for a network with more nodes or links, further optimization of core storage is needed. It can be done by either eliminating intermediate data storage or using "overlay" or both. This will allow the developed CMANA to handle a larger and more complex network.

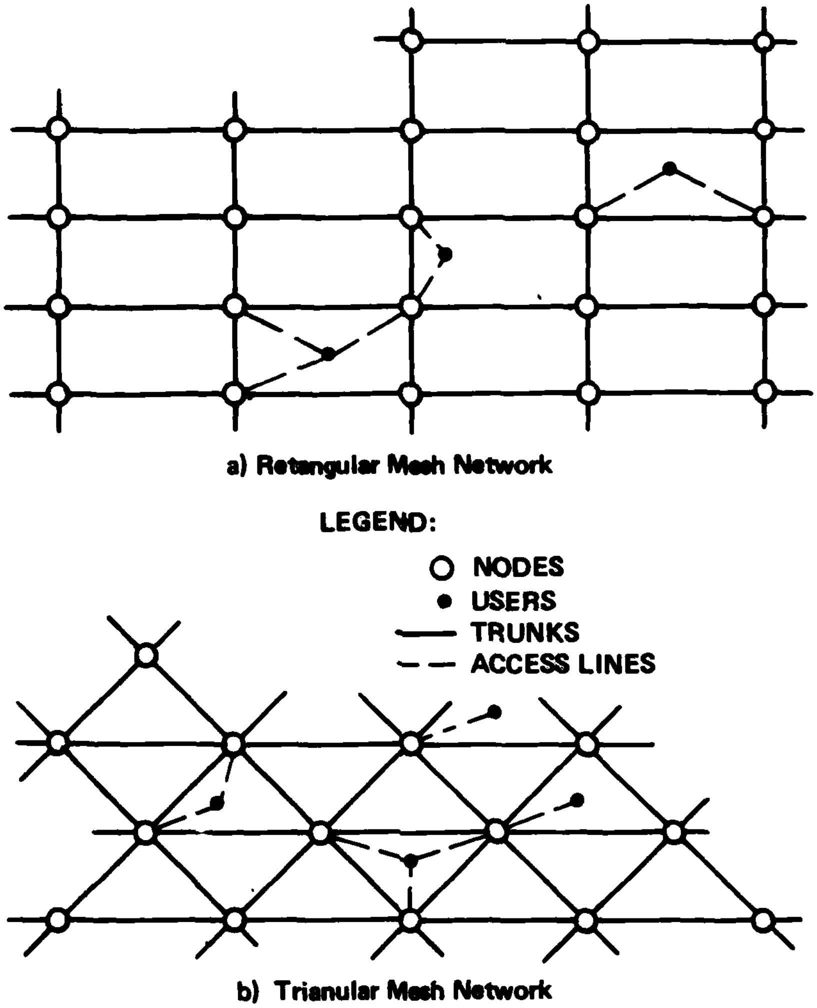

Figure 7-1. Concept of Survivable Communications Mesh System

2. Study of Replication Criteria. One of many features of the current CMANA program is to automatically stop the Monte Carlo replication of removing damaged links with a specified damage percentage until the five successive comparison of changes of ANA is less than 5%. A precautionary measure is also included in that the total number of replication is limited to 100. Experience indicated that the number of replication is no more than twenty. To check the accuracy of the resulted ANA with this "5% criterion", two tests have been conducted. One case was run for 100 replications and the same case was run with 1% and 0.1% criteria. These results are quite close the results of "5%" run. To save computer time "5% criterion" have been adapted for all ANA runs. It was also found that the optimal criterion depends on the number of nodes, number of links, network topology, and possibly some other factors. Hence, it is recommended that an investigation be initiated to determine the criterion or criteria for stopping the Monte Carlo process. The finding can be used to modify the program to obtain better defined accuracy.

3. Further Optimization of Re-routing Process. At the present time, the re-routing process is as following. For a particular damage case, a number of damaged links are determined or selected by a random number generator. Then the re-routing paths for all damaged links are identified and grouped as one-relay path, two-relay path and so on. Finally, the disrupted traffic for all damaged links is re-routed through the identified re-routing paths from the shortest paths, i.e. one-relay paths to the longest paths available. This process may not give the optimum solution, i.e. the highest network availability under certain circumstances. Some research is suggested for re-routing the disrupted traffic in the most efficient way in order to obtain the highest possible network availability.

The current CMANA program with or without the above mentioned refinements can be enhanced along the following directions to provide more capability and utility for network planning and performance evaluation.

1. Accommodate Circuit Traffic Requirement. The current Average Network Availability methodology is based on or expressed in terms of link traffic provided by a network in a stressed environment. The link traffic means traffic between adjacent nodes. This basis has been adopted because of the available traffic requirement data. In practice, in a network considered in the current work, or similar ones, in contrast with the link traffic, there is circuit traffic which is the traffic starting from one of the nodes through several different nodes then ending at another node. In other words, circuit traffic consists of a few links of the network in tandom. There is certainly, some circuit traffic with either one end or both ends of the circuits located outside of the network considered. Both kinds of circuit traffic have not been treated in the current CMANA Program. The current approach assumes the non-existence of such circuit traffic. The current CMANA can be easily modified to handle both link traffic and circuit traffic and compute the network availability. However, the definition of network availability shall be revised accordingly, to properly reflect the circuit traffic.

2. Handle Common User Network. It is obvious that the CMANA treats all link traffic and cirucit traffic if enhanced, as dedicated traffic. All traffic or service is assumed to be continuously required. This program can be modified to handle the common user network, for example, AUTODIN, AUTOVON, and AUTOSEVOCOM. For this application, network data will include network topology and capacities of all links; the traffic data will be the calling statistics and record and data transfering statistics. These statistics include density function or distribution function description of calling/transfering rate, duration of calls and length of data transmission, temporal distribution of traffic of subscribers

of the system. The enhanced program can provide the following information of system measures of networks, such as grade of service, delay, channel utilization; all these network performance measures will be quantified in terms of statistics such as density function, average, and standard deviation. The grade of service gives the probability of a subscriber receiving a busy signal, i.e. not being able to connect to a called subscriber; the delay, specifies the waiting time for transmitting a digital message. These two measures are system performance as viewed by the common users. The third measure, channel utilization, is a network measure from the viewpoint of a network operator or planner. These measures can also be used for a network under a specified stressed condition. Other kinds of network performance measures, of course, can be defined and incorporated into the simulation program.

3. Handle compartmentalized and prioritized traffic. The current CMANA program treats all link traffic on an equal basis. This aspect can be easily modified to handle compartmentalized traffic and prioritized traffic. Two examples of compartmentalized traffic are high rate and large volume computer data exchange, low or medium rate digital data, and classified traffic of different security. Performance for each kind of service can be evaluated by the program, however, the handling procedure for each kind of service should be defined. Prioritized traffic can be treated as compartmentalized traffic, however, under a stressed condition, disrupted traffic of higher priority can be re-routed and switched by bumping the traffic of the next priority. This bumping process can be carried on to the traffic or lowest priority. Therefore each priority traffic will have their own average network availability.

4. Evaluate Network With Nodes Having Different Re-routing and Switching Capability. The developed CMANA Program assumes each node with an identical re-routing and switching capability. This is not an optimized network design. A realistic network may consist of a few different classes of nodes. The lowest class of nodes will not be provided with any re-routing and switching capability; the highest class of nodes will be provided with the most extensive re-routing and switching capability. The other classes of nodes will have various degrees of capability of re-routing and switching. The CMANA program can be modified to evaluate such networks.

5. Provide Interactive Network Design Capability. The program enhanced as above, partially or wholly, can be further modified to result in an interactive program which can be employed to design a complete new network or to modify an existing network for various purposes. The following are a few examples of design or modification goals; least cost system, most survivable system, system with shortest delay, etc.

It is obvious that the current CMANA program can be used as a nucleus based on which, many more capable programs servicing various different purposes can be developed. These programs will be useful tools for network investigation.

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REFERENCES

1-1 TRW, "Evaluation of DCS III Transmission Alternatives, Phase IA Final Report", TRW Doc. No. 35142, May 1980

TRW, "Evaluation of DCS III Transmission Alternatives, Appendix A, Transmission Media", TRW Doc. No. 35142, May 1980

TRW, "Evaluation of DCS III Transmission Alternatives, Appendix B, Regulatory Barriers", TRW Doc. No. 35142, May 1980

TRW, "Evaluation of DCS III Transmission Alternatives, Appendix C, Regional Consideration and Characterization", TRW Doc. No. 35142, May 1980

1-2 TRW, "Evaluation of DCS III Transmission Alternatives, Phase IB Final Report", TRW Doc. No. 35142, September 1980

1-3 TRW "Evaluation of DCS III Transmission Alternatives, Phase II Task 1 Final Report", TRW Doc. No. 35142, August 1981

3-1 Defense Communications Engineering Center, "Design Objectives for DCS LOS Digital Radio Links", EP 27-77, December 1977

3-2 Defense Communications Engineering Center, "DCS Digital Transmission System Performance", TR 12-76, November 1976

3-3 Defense Communications Agency, "DCS Digital Transmission Performance Standard", Draft Military Standard March 1980 MIL-STD-188-XXX

3-4 D. Cowan "The LD-4 System", ICC 1977

3-5 M. Kawashima and T. Misugi, "Light Emitting Diode Transmitter Reliability", ICC 1980

3-6 A. J. Giger and W. T. Barnett, "Effects of Multipath Propagation on Digital Radio", IEEE Trans. Com. Vol. COM-29, No. 9, September 1981

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ANNEX A SUPPORTING DATA OF SYSTEM LIFE CYCLE COST

This annex presents detailed costing data used as the base of the system life cycle cost estimate of the proposed seven alternative transmission systems. The data of the annex is provided to support the major cost elements of system life cycle costs presented in Section 6 of this report. All costs given below are rounded to the nearest thousand dollars.

A.1 BASIC MATERIAL COSTS

The basic material costs of the three transmission media are shown in Tables A-1, A-2, and A-3 respectively. Costs shown are based on projected year 2000 technology but expressed in terms of 1980 dollars. Acquisition, deployment, and sustaining costs of the seven proposed systems as presented in the following Sections A.2 and A.3, are derived from these material costs. Note that definitions and numerical values of various loading factors, quantity factors, and distance factors are defined in Section 5.3 of the report.

A.2 SUPPORTING COST DATA OF HAWAII ALTERNATIVE SYSTEMS

The supporting cost data of the required material cost, acquisition cost, and sustaining cost of three proposed alternative systems, microwave LOS, millimeter wave LOS, and fiber optics, proposed for Oahu Island, Hawaii are shown in Tables A-5, A-6, and A-7 respectively.

A.3 SUPPORTING COST DATA OF CENTRAL GERMANY ALTERNATIVE SYSTEMS

The four proposed alternative transmission systems for Central Germany are microwave LOS, millimeter wave LOS, microwave and millimeter wave mix system I and II. The supporting cost data of these systems are presented in Tables A-7 to A-10 inclusive.

Table A-1. Basic Unit Cost of Microwave LOS Radio

ITEM	UNIT PRICE ($K)
Microwave Terminal Electronics Equipment	50.0
Antenna:* 8 Foot	4.0
10 Foot	6.0
12 Foot	8.0
Transmission Line	$21.0/meter
HVAC/Dehydrator	1.4
Order Wire Equipment	2.5
Alarm and Control (Remote) 16 point	1.5
Primary and Auxiliary Power (3 kW)	10.0
Tower: 15 meter	15.0
20 meter	20.0
25 meter	30.0
30 meter	40.0
35 meter	42.0
40 meter	44.0
50 meter	46.0
60 meter	48.0
66 meter	53.0

*Because the RF environment of Germany and Oahu Island, Hawaii, contain high levels of microwave densities, the microwave antenna sizes, i.e., dimeters selected have been increased from the system designs in order to reduce the probability of interference to and from other systems. This note is applicable to all following tables.

Table A-2. Basic Unit Cost of Millimeter LOS Radio

ITEM	UNIT PRICE ($K)
Millimeter Wave Terminal Electronics Equipment*	$65.0K
Order Wire Equipment	2.5
Alarm and Control (Remote) 16 point	1.5
Primary and Auxiliary Power (2.5kW)	8.0
Tower: 15 meter	15.0
20 meter	20.0
25 meter	30.0
30 meter	40.0
35 meter	42.0
40 meter	44.0
50 meter	46.0
60 meter	48.0
66 meter	53.0

*Including antennas and transmission lines, in quantity, unit price reduced from $140.0K to $65.0K

Table A-3. Basic Unit Cost of Fiber Optics

ITEM	UNIT PRICE ($K)
Optical Fiber (6-fiber) Cable ($/meter)	5.00
Connectors	200
Electro-Optical Terminal	34,200
Duct and Hardware ($/meter)	2.18

Table A-4. Supporting Cost Data of Proposed Microwave LOS System for Oahu, Hawaii

COST ITEM	QUANTITY	COST ($K)
<u>Material</u>		
a. Microwave Radio Equipment	46	2,300
b. Antennas, 8 ft	46	184
c. Feed System	2,304 (m)	48
d. Dehydrator/HVAC	16	22
e. Order Wire Equipment	16	40
f. Alarm and Control	16	24
g. Primary and Auxiliary Power *	3	30
h. Towers		
15m	2	30
20m	1	20
30m	13	520
<u>Acquisition</u>		
a. Electronics Equipment, (a+b+c+d+e+f+g)x 1.7 = A		4,503
b. Tower, h x 1.4		798
c. Installation Material, 0.05 x (a+b+c+d+e+f+g)x 1.037=C		137
d. Test Equipment, 0.1 x A = D		450
e. Spares, 0.15 x A = E		675
f. Total Acquisition Cost, TAC = A+B+C+D+E		6,564
<u>Deployment</u>, 0.3 x TAC		1,969
<u>Sustaining (Annual)</u>		
Spare, 0.5 x E		338
Test Equipment, 0.1 x D		45
Personnel, 16 x P **		38
Vehicle, 16 x V		2
Total Sustaining Cost (Annual)		423

*Assumed that three sites need primary and auxiliary power generating equipment.

**P = $2,400 annual operation and maintenance personnel cost per site.
V = $108 annual operating cost per maintenance vehicle.

This note applies to all following tables, see Sections 5.6.1 and 5.6.2 for details.

Table A-5. Supporting Cost Data of Proposed Millimeter Wave LOS System of Oahu, Hawaii

COST ITEM	QUANTITY	COST ($K)
Material		
a. Millimeter Wave Radio Equipment	66	4,290
b. Order Wire Equipment	26	65
c. Alarm and Control	26	39
d. Primary and Auxiliary Power*	11	88
e. Towers		
15m	1	15
20m	13	260
30m	12	480
Acquisition		
a. Electronics Equipment, (a+b+c+d) x 1.7 = A		7,619
b. Towers, e x 1.4 = B		1,057
c. Installation Material, 0.5 x (a+b+c+d) x 1.037 = C		232
d. Test Equipment, 0.1 x A = D		762
e. Spare, 0.15 x A = E		1,143
f. Total Acquisition Cost, TAC = A+B+C+D+E		10,813
Deployment 0.3 x TAC		3,244
Sustaining (Annual)		
Spares Consumption, 0.5 x E		571
Test Equipment, 0.1 x D		76
Personnel Costs, 26 x P		62
Vehicle Costs, 26 X V		3
Total Sustaining Cost		712

*Assumed that 11 sites need primary and auxiliary power generating equipment

Table A-6. Supporting Cost Data of Proposed Fiber Optical System for Oahu, Hawaii

COST ITEM	QUANTITY	COST ($K)
Material		
a. Electro-Optic Tx/Rx Terminal	42	1,436
b. Connectors (6/Terminal)	252	50
c. Fiber Optic Cable	227.1 (km)	1,136
d. Duct and Hardware	22.71 (km)	50
Acquisition		
a. Electronics Equipment, (a+b) x 2.3 = A		3,420
b. Fiber Optic Cable, a x 1.1 x 2.3 = B		2,873
c. Duct and Hardware, dx 1.05 x 2.3 = C		120
d. Installation Equipment, e x 0.15 = D		18
e. Spares, A x 0.1 + (B+C)x 0.01 = E		372
f. Test Equipment (A+B) x 0.08 = F		503
g. Total Acquisition Cost, TAC = A+B+C+D+E		7,305
Deployment, 227.1 x $25		5,675
Sustaining (Annual)		
Spare, 0.5 x E		186
Test Equipment, 0.1 x F		50
Personnel, 15 x P		36
Vehicle, 15 x V		2
Total Sustaining Cost (Annual)		274

Table A-7. Supporting Cost Data of Proposed Microwave LOS System of Central Germany

COST ITEM	QUANTITY	COST ($K)
<u>Material</u>		
a. Microwave Radio Equipment	100	5,000
b. Antennas		
8 ft.	72	238
10 ft.	22	132
12 ft.	6	48
c. Feed System	7980 (m)	168
d. Dehydrator/HVAC	33	46
e. Order Wire Equipment	33	82
f. Alarm and Control	35	50
g. Primary and Auxiliary Power	12	120
h. Towers		
20m	2	40
30m	11	440
40m	14	616
50m	3	138
60m	2	96
66m	1	33
<u>Acquisition</u>		
a. Electronics Equipment (a+b+c+d+e+f+g) x 1.7 = A		10,087
b. Towers h x 1.4 = B		1,936
c. Installation Material 0.05 x (a+b+c+d+e+f+g)x 1.037 = C		308
d. Test Equipment 0.10 x A = D		1,009
e. Spares 0.15 x A = E		1,514
f. Total Acquisition TAC = A+B+C+D+E		14,853

Table A-7. Supporting Cost Data of Proposed Microwave LOS System of Central Germany (Continued)

COST ITEM	QUANTITY	COST ($K)
Deployment (TAC x 0.3		4,456
Sustaining (Annual)		
Spare Consumption 0.5 x E		756
Test Equipment 0.1 x D		101
Personnel 33 x P		79
Vehicle 33 x V		40
Total Sustaining Cost (Annual)		976

Table A-8. Supporting Cost Data of Proposed Millimeter Wave LOS System for Central Germany

COST ITEM	QUANTITY	COST ($K)
Material		
a. Millimeter Wave Radio Equipment	178	11,570
b. Order Wire Equipment	79	198
c. Alarm and Control	79	119
d. Primary and Auxiliary Power*	38	304
e. Towers		
20m	61	1,220
25m	3	90
30m	5	200
40m	7	308
50m	2	92
66m	1	53
Acquisition		
a. Electronics Equipment, (a+b+c+d)x 1.7 = A		20,723
b. Towers, e x 1.4 = B		2,748
c. Installation Material, 0.5 x (a+b+c+d)x 1.037 = C		632
d. Test Equipment, 0.1 x A = D		2,072
e. Spare, 0.15 x A = E		3,108
f. Total Acquisition Cost, TAC=A+B+C+D+E		29,283
Deployment 0.3 x TAC		8,785
Sustaining (Annual)		
Spares Consumption, 0.5 x E		1,554
Test Equipment, 0.1 x D		207
Personnel Costs, 0.075 x 79 x P		190
Vehicle Costs, 79 x V		10
Total Sustaining Cost		1,961

*Assumed that 79 sites need primary and auxiliary power generating equipment

Table A-9. *Supporting Cost Data of Proposed Microwave and Millimeter Wave Mix I System for Central Germany*

COST ITEM	QUANTITY	COST ($K)
Material		
a. Microwave Radio Equipment	56	2,800
b. Microwave Antennas		
8 ft	32	128
10 ft	18	108
12 ft	6	48
c. Mircowave Feed System	3062 (m)	64
d. Millimeter Wave Radio Equipment	32	2,080
e. Dehydrator/HVAC (only at microwave sites)	24	34
f. Order Wire Equipment	31	78
g. Alarm and Control	31	47
h. Primary and Auxiliary Power	14	140
i. Towers		
20m	4	80
25m	3	90
30m	7	280
40m	11	484
50m	3	138
60m	2	96
66m	1	53
Acquisition		
a. Electronics Equipment, (a+b+c+d+e+f+g+h)x 1.7 = A		9,394
b. Towers and mounts, i x 1.4 = B		1,709
c. Installation Material, 0.05 x A x 1.037 = C		287
d. Test Equipment, 0.1 x A = D		939
e. Spare, 0.15 x A = E		1,409
f. Total Acquisition Cost, TAC = A+B+C+D+E		13,738
Deployment, 0.3 x TAC		4,121
Sustaining (Annual)		
Spare Consumption, 0.5 x E		705
Test Equipment, 0.1 x D		94
Personnel, 0.075 x 31 x P		74
Vehicle, 31 x V		4
Total Sustaining Cost (Annual)		877

Table A-10. Supporting Cost Data of Proposed Microwave and Millimeter Wave Mix II System for Central Germany

COST ITEM	QUANTITY	COST ($K)
Material		
a. Mircowave Radio Equipment	26	1,300
b. Microwave Antennas		
8 ft	10	40
10 ft	12	72
12 ft	4	32
c. Microwave Feed System	2,894 (m)	61
d. Millimeter Wave Radio Equipment	86	5,590
e. Dehydrator/HVAC (only at microwave sites)	16	22
f. Order Wire Equipment	45	113
g. Alarm and Control	45	68
h. Primary and Auxiliary Power *	20	200
i. Towers		
20m	21	420
25m	2	60
30m	6	240
40m	12	528
50m	2	92
60m	1	48
66m	1	53
Acquisition		
a. Electronic Equipment, (a+b+c+d+e+f+h)x 1.7 = A		12,745
b. Tower, i x 1.4 = B		2,017
c. Installation Material, 0.05 x (a+b+c+d+e+f+g+h)x 1.037=C		389
d. Test Equipment, 0.1 x A = D		1,275
e. Spare, 0.15 x A = E		1,912
f. Total Acquisition Cost, TAC = A+B+C+D+E		18,338
Deployment, 0.3 x TAC		5,501
Sustaining (Annual)		
Spare Consumption, 0.5 x E		956
Test Equipment, 0.1 x D		127
Personnel, 0.075 x 45 x P		108
Vehicle, 45 x V		6
Total Sustaining Cost (Annual)		1,197

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ANNEX B. NETWORK SIMULATION PROGRAM

This annex presents the description and discussion of the Network Simulation (NETS) program which has been applied to evaluate the performance of propcsed and improved alternative systems. The results of such analyses are also provided here.

It should mention the following points at the beginning of this annex:

1. The NETS program is offered by the TRW's subcontractor, Page Communications.

2. The NETS program performs the network evaluation in a different way as specified by TRW. Therefore, comparison of results of CMANA and NETS is not meaningful.

3. The major differences between the CMANA and NETS programs are:

   a. The CMANA can assign a different number of traffic channels and spare capacity to each link; the NETS can only group all links of a network into several groups, then assigns all links of each group with the same number of traffic channels. Furthermore, the NETS specifies spare capacity on a network basis, i.e., all links with the same percentage of their traffic channels as their spare.

   b. The so called "Inferred Traffic Demand" is used for "Capacity Survivability" in the NETS program. This is different from the link basis of the CMANA program. However, it is not clear how the "Inferred Traffic Demand" is derived from the specified link traffic and spare requirement for each of the alternative systems. No "Inferred Traffic Demand" is given for any of the alternative systems.

4. Since NETS is a compary private program, no program detail is provided to TRW. Hence, no evaluation of this program is made by TRW project personnel.

The following pages are direct fascimile reproduction of Page's report except that their results, in the form of computer print-out sheets,have been combined and presented in tabular form.

1. Description of the Network Simulation Program (NETS)

The NETS software package allows communication network simulations to determine degradation and communication survivability between individual pairs of nodes in any given system of up to 50 nodes. Degradation and outage probabilities can be entered on a link by link basis to realistically reflect different technical and survivability aspects under adverse conditions. Various emergency, sabotage, and war scenarios may thus be investigates in great detail.

Conversely, summary network degradation factors, such as "20% outage probability for all links in the system" may be specified for a general communication survivability and network design study.

NETS performs its functions through Monte Carlo simulations. The resulting outputs produce detailed statistics on communications survivability between individual pairs of nodes, likely degradations, and required increases in routing complexities for the system under attack. They also produce summary statistics on average network availabilities for specified probabilities of network damage.

The obtained statistics provide valuable clues for network enhancement and design. For example, various design options may be investigated on a probabilistic basis. For a specified or implied traffic demand the chosen network topology and link capacities greatly influence the communication survivability of the system. Thus with subsequent NETS simulations the various design options can effectively be evaluated in a realistic, quantitative manner. For this reason, NETS aids -- and makes possible -- the economic design of threat-resistant communication systems.

1.1 The Optimum Routing Algorithm Used by NETS

The heart of the program is a universal routing algorithm that determines optimum routes between all pairs of nodes in any given network configuration. The routing algorithm incorporates the following characteristics:

- In a damaged network it always finds a path between two pairs of surviving nodes, whenever there is a potential path physically left (no matter how circuitous that path may be)
- It determines the least restrictive bottleneck route. This is the path in which the bottleneck, or weakest link of that route, is better (less restrictive) than the bottlenecks of other possible routes
- If there are several 'best bottleneck' routes, it finds the one that minimizes the number of required links, thus minimizing the number of required links.

The number of possible paths, for going from each node to all others, is of astronomical proportions in larger systems. For example, there are 1.65×10^{63} paths in a fully interconnected 50-node system. Consequently, the determination of optimum routing directories is not a trivial task. Any simple, brute-force inspection approach would be impossible, even with high speed computers, since this would require processing times greater than the age of the universe.

The incorporated routing algorithm employs special short-cut techniques that reduce the problem to manageable size. Without sacrificing optimality, the algorithm allows the determination of routing directories within seconds, thus improving other time-saving operations research approaches by several orders of magnitude. This makes it possible, to employ the algorithm in Monte Carlo communication survability programs, where not only one, but many randomly degraded network configurations have to be evaluated in order to achieve statistically meaningful results.

1.2 Relative Link Loading Figures

To describe the characteristics of a particular link -- relative to the characteristics of other links in the system -- a relative link or loading figure is used (RL-figure). The RL-figure can be thought of as being somewhat similar to the measure of 'resistance' in electrical systems: the smaller the resistance, the better or stronger the potential for conducting (communicating).

In voice communication systems, for example, a small RL-figure may represent a link with a greater number of channels. In message switching systems, a small RL-figure may mean no or only a small backlog or time delay for the subsequent transmission of newly arriving messages on that link. Conversely, an extremely high RL-figure may be used to describe a destroyed link with no communications possible at all.

The optimum routing directory is computed by considering the RL-figures of each link in the system. Following the process described in the previous section, each selected path between two pairs of nodes will be one in which the encountered bottleneck, that is the link with the lowest RL-figure, is less restrictive than the bottleneck RL-figure of other possible paths between the two nodes in question. It is also a path with the fewest number of links for the indicated bottleneck capacity. The included Figure 1 provides a small test case for illustration. Figure 2 presents the developed routing directory of an extended network (additional link D-E) under a severe attack scenario.

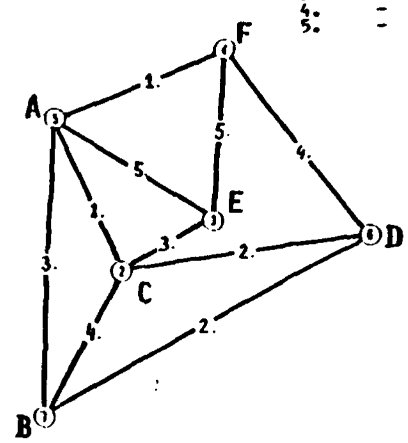
Figure 1

Q-MATRIX

09-04-81

TO NODE	2	3	4	5	6	7
FROM 2	--	3.	.	1.	2.	4.
FROM 3	3.	--	5.	5.	.	.
FROM 4	.	5.	--	1.	4.	.
FROM 5	1.	5.	1.	--	.	3.
FROM 6	2.	.	4.	.	--	2.
FROM 7	4.	.	.	3.	2.	--

RL-FIGURE		CHANNELS
1.	-	300.
2.	-	250.
3.	-	200.
4.	-	150.
5.	-	100.



ROUTING DIRECTORY

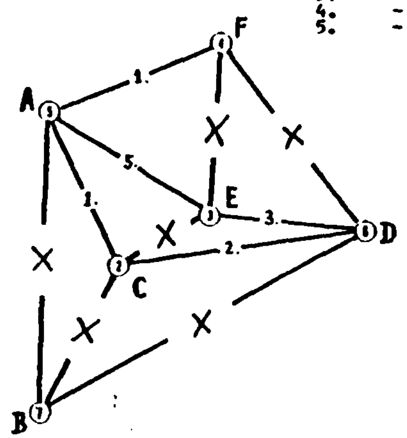
FROM	TO	LINKS	BOTTLENECK RL	BOTTLENECK TI	ROUTE
2 -	3 :	1	3.	200.00	2 - 3 -
2 -	4 :	2	1.	300.00	2 - 5 - 4 -
2 -	5 :	1	1.	300.00	2 - 5 -
2 -	6 :	1	2.	250.00	2 - 6 -
2 -	7 :	2	2.	250.00	2 - 6 - 7 -
3 -	4 :	3	3.	200.00	3 - 2 - 5 - 4 -
3 -	5 :	2	3.	200.00	3 - 2 - 5 -
3 -	6 :	2	3.	200.00	3 - 2 - 6 -
3 -	7 :	3	3.	200.00	3 - 2 - 6 - 7 -
4 -	5 :	1	1.	300.00	4 - 5 -
4 -	6 :	3	2.	250.00	4 - 5 - 2 - 6 -
4 -	7 :	4	2.	250.00	4 - 5 - 2 - 6 - 7 -
5 -	6 :	2	2.	250.00	5 - 2 - 6 -
5 -	7 :	3	2.	250.00	5 - 2 - 6 - 7 -
6 -	7 :	1	2.	250.00	6 - 7 -

Q-MATRIX

TEST # 2.2 09-04-81
CASE NO.: 6

TO NODE	2	3	4	5	6	7
FROM 2	--	(XX)	.	1.	2.	(XX)
FROM 3	(XX)	--	(XX)	5.	3.	.
FROM 4	.	(XX)	--	1.	(XX)	.
FROM 5	1.	5.	1.	--	.	(XX)
FROM 6	2.	3.	(XX)	.	--	(XX)
FROM 7	(XX)	.	.	(XX)	(XX)	--

RL-FIGURE		CHANNELS
1.	-	300.
2.	-	250.
3.	-	200.
4.	-	150.
5.	-	100.



ROUTING DIRECTORY

FROM - TO	LINKS	BOTTLENECK RL	BOTTLENECK T1	ROUTE
2 - 3 :	2	3.	200.00	2 - 6 - 3 -
2 - 4 :	2	1.	300.00	2 - 5 - 4 -
2 - 5 :	1	1.	300.00	2 - 5 -
2 - 6 :	1	2.	250.00	2 - 6 -
2 - 7 :				NO PATH AVAILABLE
3 - 4 :	4	3.	200.00	3 - 6 - 2 - 5 - 4 -
3 - 5 :	3	3.	200.00	3 - 6 - 2 - 5 -
3 - 6 :	1	3.	200.00	3 - 6 -
3 - 7 :				NO PATH AVAILABLE
4 - 5 :	1	1.	300.00	4 - 5 -
4 - 6 :	3	2.	250.00	4 - 5 - 2 - 6 -
4 - 7 :				NO PATH AVAILABLE
5 - 6 :	2	2.	250.00	5 - 2 - 6 -
5 - 7 :				NO PATH AVAILABLE
6 - 7 :				NO PATH AVAILABLE

Figure 2

1.3 Types of Network Investigations

The NETS program can support different types of investigations. This is determined by the node numbering scheme employed. If there is a node '1' in the network, then a routing directory will be computed for going from node '1' to all other nodes in the system.

If the number of nodes in the system starts with '2', however, then a more extensive routing directory for going from any node to any other node in the system will be developed.

As figure 3 indicates, this capability can be used in different types of network simulations:

(A) for studying hierarchical traffic flows as typically encountered in military command and control situations

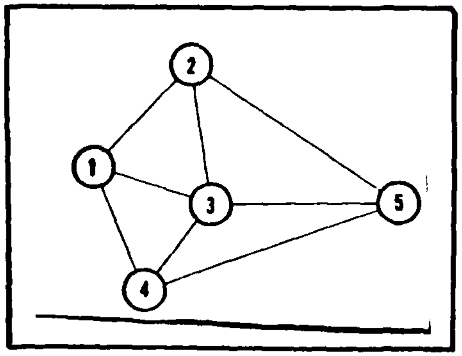
(B) for evaluating a more 'democratic' user network with traffic flows from any node to any other node

(C) for investigating a network that is part of a larger complex, and where its communication survivability with the 'outside world' is of particular interest.

For the DCS III task the type (B) of network simulations has been used exclusively. In this mode routing directories are developed that contain all node pairs of the system.

Figure 3

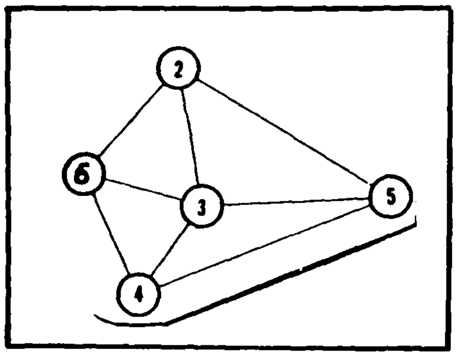
TYPES OF NETWORK INVESTIGATIONS



(A)

NODE 1 TO ALL OTHERS

(COMMAND & CONTROL SITUATIONS)

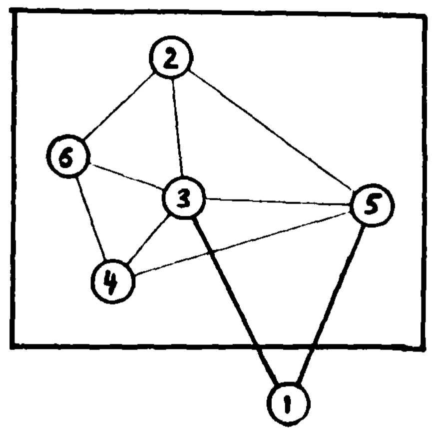


(B)

ANY NODE TO ANY OTHER

(TRAFFIC WITHIN THE SYSTEM)

(C)



'OUTSIDE WORLD' TO PARTIAL NETWORK

(TRAFFIC BETWEEN THE 'OUTSIDE' AND EACH NODE)

PSEUDO NODE 1, REPRESENTI   THE 'OUTSIDE'; BUT REAL LINKS INTO THE NETWORK

2. ANA analysis

The concept of Average Network Availability (ANA) was suggested in order to obtain a comprehensive, quantitative measure for comparing different network design options -- even relatively small design variations -- in a simple, yet meaningful and precise manner. The basic idea was to find a way that would make it possible to derive ANA probability figures for various network configurations and damage scenarios. This would enable the design and accurate comparision of threat-resistant network configurations. It would also facilitate the most effective use of future DCS dollars for network expansions.

2.1 ANA Definition

An Average Network Availability measure can best be envisioned in the form of a composite probability figure that expresses the average communication survivability of a network in the face of a given probability of damage. The subcomponents of ANA can be thought of as three other probabilities:

- Path Survivability (PSV), a measure of the network topology and its resilience towards damage through alternate routing to bypass destroyed portions of the system
- Path Time Availability (PTA), a measure of technical reliability for maintaining communications over the surviving paths
- Capacity Survivability (CSV), a measure of (sufficient) capacity survivability to sustain given traffic demands over the surviving portions of the system.

All three components are represented by a figure in the range between 1 and 0. If one succeeds in calculating each probability component -- making sure that they are truly independent of each other -- then the ANA could simply be computed as:

$$\boxed{ANA = PSV * PTA * CSV}$$

The beauty of this formula is that it not only establishes the desired single, comprehensive ANA figure for network comparison and evaluation, but also provides very definite clues, in which specific area a design is lacking. Since each of the probabilities must be a figure in the range between 0. and 1., the smallest factor of the three components is usually the culprit that tears the ANA down the most. This clearly pinpoints the most promising area for effective network improvements. The information can be used to guarantee that future DCS dollars are spent precisely in those areas where the payoff is at a maximum, and where the improvements do the most good from a communication survivability point of view.

The above stated line of thought can be readily verified because the ANA probability, according to the formula, can never be greater than its worst component. Even if the two other components were at their best (a value of 1) the ANA still would only be equal to the worst candidate, as multiplication of the three factors suggests.

2.2 ANA Implementation

While it is a relatively simple matter to formulate and discuss the ANA concept from a theoretical point of view, it is considerably more complex and difficult to achieve this task in practice. For this a method of network survivability simulations must be devised that produces the postulated network damage scenarios in Monte Carlo fashion, considers best alternate routing adaptations to counteract those damages, and subsequently evaluates the communications survivabilities in terms of the outlined factors.

Fortunately, the optimum routing directory, produced by the NETS software package, provides all the source information necessary to pinpoint and isolate the three survivability components. This can be verified readily by a printout of the directory itself which lists the destroyed or

rerouted communication paths for all node pairs in the system (figure 4).

The path survivability factor PSV, for example, can be derived in a relatively straight-forward manner from the routing or 'NO PATH AVAILABLE' information of the directory.

The path time availability PTA changes with changing routing complexities. The PTA probability figure can therefore be computed from the indicated number of links required for each surviving path.

Finally, the bottleneck capacities of surviving paths are available. This information can be used to calculate the capacity survivability figure CSV.

In the following sections the method and required computations are outlined in greater detail.

Information Sources for Developing the Survival Probability Figures

Path Time Availability (PTA)

Capacity Survivability (CSV)

Path Survivability (PSV)

ROUTING DIRECTORY

5. MIN.MICROWAVE, GE
CASE NO.: 1

FROM	TO	LINKS	BOTTLENECK RL	BOTTLENECK TL	ROUTE
2 -	3 :	3	6.	$\boxed{9.00}$	2 - 19 - 4 - 3 -
2 -	4 :	2	6.	$\boxed{9.00}$	2 - 19 - 4 -
2 -	5 :	6	13.	4.00	2 - 11 - 3 - 25 - 7 - 6 - 5 -
2 -	6 :	5	13.	4.00	2 - 11 - 3 - 25 - 7 - 6 -
2 -	7 :	4	13.	4.00	2 - 11 - 3 - 25 - 7 -
2 -	8 :	5	13.	4.00	2 - 11 - 3 - 25 - 7 - 8 -
2 -	9 :	6	13.	4.00	2 - 11 - 3 - 25 - 7 - 8 - 9 -
2 -	10 :	6	13.	4.00	2 - 11 - 3 - 25 - 7 - 8 - 10 -
2 -	11 :	4	6.	$\boxed{9.00}$	2 - 19 - 4 - 3 - 11 -
2 -	12 :	1	3.	12.50	2 - 12 -
2 -	13 :	1	11.	5.00	2 - 13 -
2 -	14 :	1	2.	13.00	2 - 14 -
2 -	15 :	4	6.	$\boxed{9.00}$	2 - 19 - 4 - 3 - 15 -
2 -	16 :	1	2.	13.00	2 - 16 -
2 -	17 :	3	11.	5.00	2 - 19 - 4 - 17 -
2 -	18 :				NO PATH AVAILABLE
2 -	19 :	1	3.	12.50	2 - 19 -
2 -	20 :	2	10.	5.50	2 - 19 - 20 -
2 -	21 :				NO PATH AVAILABLE
2 -	22 :	3	16.	1.50	2 - 11 - 3 - 22 -
2 -	23 :	3	15.	2.50	2 - 11 - 3 - 23 -
2 -	24 :	2	16.	1.50	2 - 14 - 24 -
2 -	25 :	3	13.	4.00	2 - 11 - 3 - 25 -

Figure 4

2.3 Computation of Inferred Traffic Demand

For the analysis of the 'Capacity Survivability' (CSV) component some information must be available about the average traffic demand between all DCS node pairs in the system. This information is necessary to judge whether rerouting of calls in the damaged network provides sufficient capacity to satisfy the demand.

Since traffic information was not provided, it must be derived indirectly. Such traffic estimates can be based on the given network configuration itself. The reasoning here is that the network has evolved into its present form to satisfy actually occurring traffic demand. It can be assumed that, in the past, extensions and upgrades of the network have been made as actual traffic demand necessitated such adjustments. Hence, the network itself fairly well represents the traffic within it. (To a lesser extent, this holds true also for planned 'minimum' network configurations to be implemented for handling future estimated traffic flows, or for the replacement of obsolete systems).

To obtain the traffic demand information from a given network configuration, the following procedure has been used:

(1) Develop an optimum routing directory for the 'minimum' or 'existing' network in question. The path selected for each node pair provides the least restrictive bottleneck route for connecting these two nodes (primary optimization objective), using the fewest number of links (secondary optomization objective). It means that for each node pair the maximum number of channels has been established when using one (the optimum) routing path.

(2) Normalize the obtained figures to a reduced set of traffic demand capacities between all pairs of nodes that can be maintained simultaneously by the specified network. This normalization process takes 'contention' (i.e. competition for limited resources of the network) into consideration.

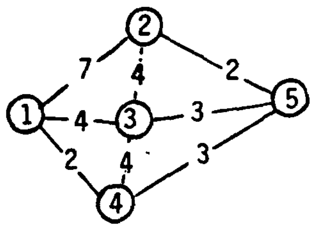
Figure 5 provides a simplified illustration for discussing the problem: the small network shown consists of eight links and the total number of available channels in the network is 29. The corresponding routing directory, for going from any node to any other, lists 10 routes or paths. The routing algorithm has chosen those paths in such a way as to achieve the highest number of channels possible for connecting the two nodes in question. This can readily be verified through inspection.

As a first approximation one could say that the routing directory itself -- with its indicated bottleneck capacities -- is representative of the underlying traffic demands for all pairs of nodes in the system. However, those figures have to be adjusted in order to take contention into consideration. While any single node pair by itself could have the number of channels as indicated by the routing directory, all node pairs together could not communicate in this way simultaneously. This becomes readily apparent if one calculates and totals the number of channels required as shown to the right in figure 5. Hence, the total number of required channels (53) greatly exceeds the number of available channels in the network (29).

In fact, the sum of bottleneck capacities is always greater than the sum of link capacities available to the network. To remedy this situation, calculations are performed that systematically reduce the bottleneck capacities of the routing directory. In this manner a realistic traffic demand matrix for all node pairs in the system can be established.

FIGURE 5

'EXISTING' OR PLANNED 'MINIMUM' NETWORK



NETWORK LINK	AVAILABLE CHANNELS
1-2	7
1-3	4
1-4	2
2-3	4
2-5	2
3-4	4
3-5	3
4-5	3
	$\boxed{29}$

TOTAL NUMBER OF CHANNELS IN THE NETWORK

ROUTING DIRECTORY FOR THE NETWORK ABOVE
(Maximum Number of Channels per path)

FROM - TO	LINKS	BOTTLEN.	ROUTE	REQUIRED* CHANNELS
1 - 2	1	7	1-2	7
1 - 3	1	4	1-3	4
1 - 4	2	4	1-3-4	8
1 - 5	2	3	1-3-5	6
2 - 3	1	4	2-3	4
2 - 4	2	4	2-3-4	8
2 - 5	2	3	2-3-5	6
3 - 4	1	4	3-4	4
3 - 5	1	3	3-5	3
4 - 5	1	3	4-5	3
				$\boxed{53}$

THEORETICAL NUMBER OF CHANNELS REQUIRED IF ALL PATHS OF THE ROUTING DIRECTORY WERE TO BE USED SIMULTANEOUSLY

*'Number of links per path' X 'Bottleneck capacity'

This traffic can be handled by the specified network without exceeding its inherent resources. The traffic demand matrix thus computed is kept in the main memory of the computer throughout the run. The data are used for comparison with the surviving node-to-node path capacities of a damaged network under attack.

The outlined approach circumvents the major problem of having no detailed traffic demand data available at the outset. It also bypasses the minor, but technically quite difficult problem of how to account for additional capacities per node pair through the use of alternate routes. With the number of alternate routes in larger networks assuming intractable proportions, their systematic evaluation is simply not feasible. The approach allows one to sidestep the problem completely. Since the sum of bottleneck capacities of the optimum routing directory greatly exceeds the available capacities of the specified network, additional capacities per node pair, as achieved through alternate routes, can be ignored. The latter would merely compete with the capacities of other node pairs, taking some or all of their capacities away. From an overall network traffic handling point of view, the situation would remain the same.

In this context it must clearly be understood, that any calculated traffic demand matrix represents only one out of a great number of feasible solutions for a given network configuration. It is possible (and even quite likely) that the actual traffic demand distribution is somewhat different in real life from the one computed. By the same token, however, a traffic demand matrix derived in the manner described above is at least as good and representative as any other, obtained by some different means. Only real traffic data could provide a more accurate input.

2.4 Network Survivability Factors

In this section the derivation of the individual survivability factors Path Survivability (PSV), Path Time Availability (PTA), and Capacity Survivability (CSV) will be discussed in greater detail.

2.4.1 Path Survivability (PSV)

The NETS network simulation module can be set up to produce a specified number of cases of randomly damaged network scenarios. The outage probabilities for links can be set to any desired level. This level is then held constant for the duration of a 'run'. In this way the path survivability of the network can be determined for exactly the specified link outage or damage level. Obviously, in different runs the path survivability of the network can be investigated for different levels of link outage. Such runs will result in different PSV figures for the network at those respective levels of link outage.

The employed algorithm for computing optimum routing directories always finds a path in a damaged network from any node to any other, whenever there is one physically left, no matter how circuitous this path might be. Consequently, the routing directories themselves, developed for each network damage case of the simulation run, provide an easy way for determining path survivability. If for certain node pairs the routing directory shows an available route or a 'NO PATH AVAILABLE' entry, then that information can be used directly to derive the PSV. Specifically, the path survivability

can be calculated in the following manner:

$$\boxed{PSV = \frac{NAPS}{(NPP)(NMQ)}}$$

Where: NAPS = Σ surviving paths in a given run of NMQ cases

NPP = $(N^2-N)/2$; the number of node pairs in the network

N = Number of DCS nodes (those sourcing or sinking traffic)

NMQ = Number of cases of Monte Carlo trials set for a particular run

As desired, the PSV thus derived will be a number in the range between 1 and 0. If, in spite of damage, the topology of the network always allows a path for any node pair, then NAPS becomes NPP * NMQ, resulting in a PSV of 1. At the other extreme, if no paths survived for any node pairs at all, then NAPS becomes 0, for a resulting PSV of 0.

PSV, as defined in the above manner, is a truly independent measure of connectivity survivability. In effect it defines, for a given level of link outage probability, the resistance of the network topology against damage. This is based on the fact that, literally, there is NO PATH AVAILABLE whenever the optimum routing directory says so. Consequently, it would be fallacy to think that the problem of an insufficient network configuration could be overcome by 'alternate routing' or by the 'capacity expansions' of existing links. As long as PSV is the weakest factor in the ANA equation, the latter can be significantly improved only by substantial upgrading of the network topology as measured by the PSV. This in turn means: additional links and/or better configurations of network interconnections.

2.4.2 Path Time Availability (PTA)

Path time availability is concerned with communication outages due to technical and natural environmental factors such as equipment failures or propagation degradations under normal operating conditions.

In contrast, outages caused by sabotage, jamming, or other hostile actions are best figured into the link outage probability figures for the simulation run. The latter can cover a very wide range, depending upon the attack scenarios chosen and the defensive measures employed.

Again, the objective has been to clearly isolate an independent, technical survivability factor. If the technical reliability influences the ANA equation in a major way, the latter can only be improved through advances in technology.

In practice, however, and for the purposes of the DCS III network survivability study, normal technical outages have been considered to be of minor concern. A Link Time Availability (LTA) of .999 has been assumed for all links in the system. For deriving the PTA figure, the optimum routing directories developed for each case of random network damage are, again, advantageously employed. By summing up the number of links for all surviving paths of a run, and by dividing this sum by the number of surviving paths, an average number of links per path (ALC) can be computed:

$$ALC = \frac{\Sigma \text{ LINKS}}{\text{NAPS}}$$

The path time availability then simply computes as:

$$\boxed{PTA = LTA^{ALC}}$$

Changing routing complexities due to different network damage pattern and their effects on path time availability are thereby readily included in the overall ANA evaluations.

2.4.3 Capacity Survivability (CSV)

In order to achieve a CSV figure independent from the path survivability factor (PSV), only surviving paths are considered. In this evaluation the bottleneck capacity of a surviving path is compared with the required traffic demand for this path. (For a description of the inferred traffic demand problem see Section 2.3). Based on this comparison, the bottleneck capacity is converted into a 'useful capacity' whereby:

Bottleneck Capacity $\geq$ Useful Capacity $\leq$ Required Capacity

According to these limitations, the useful capacity of a surviving path is equal to the actually available bottleneck capacity, but not exceeding the required capacity as originally derived and stored in the system for the node pair in question.

This occasional 'clipping' of the bottleneck value is necessary since capacity that exceeds the traffic demand has a low chance of being used. If this situation were left uncorrected, the wrong impression could take hold, that by adding unneeded capacities meaningful improvements of the network performance could be achieved. The 'clipping' of excess capacity is also required in a mathematical sense, because otherwise the CSV computation could possibly yield a figure greater than 1, thereby defeating the purpose of the ANA equation.

In this context it is worthwhile to note, that even with 'clipping' the simulation runs of more heavily damaged networks often yield better CSV figures than the same networks subject to less damage. Although the opposite result could be expected as a first intuitive reaction, the mystery resolves itself if one considers that the greater elimination of resource-competing paths (representing a 'bad' case of communication survival between pairs of

nodes) could actually make the remaining link capacities 'look good'. In such situations, obviously, any blind addition of more capacities to the existing links will cause very little ANA improvement.

The formula used for calculating the CSV is:

$$\boxed{CSV = \frac{1}{NMQ} \sum_{k=1}^{NMQ} \frac{\sum_{s=1}^{NPS} UC_s}{\sum_{s=1}^{NPS} RC_s}}$$

where:

NMQ - Number of cases (damaged networks) investigated

NPS - Number of surviving paths ($NPS \leq NPP$)

NPP - Number of possible paths in routing directory

UC_s - Useful Capacity of surviving path s ($UC_s \leq RC_s$)

RC_s - Required capacity of surviving path s

By using surviving paths only, independence of the capacity survivability factor CSV from the path survivability factor PSV is achieved. By limiting or 'clipping' the capacity of a surviving path UC_s to the required capacity RC_s for this path, it is ensured that the CSV factor cannot exceed a value of 1.

3.0 Results of DCS Network Analyses

In this section the various sets of proposed DCS networks and their survivability aspects are discussed in general terms. For detailed information on exact network specifications and survival figures (obtained as the result of Monte Carlo simulations of these networks under attack) consult the individual data sheets presented in Section 4. These data sheets fall into three categories:

- Minimum Network Specifications
  (Labelled 'Min.") in Section 4.1
- Proposed Network Configurations
  (Labelled 'Prop.") in Section 4.2
- Improved Network Configurations
  (Labelled 'Impr.') in Section 4.3

The 'Minimum' network specifications are the basis for calculating traffic demands. Pertinent figures are developed and used in the communication survivability simulations for both the 'Proposed' and the 'Improved' network configurations.* This assures an equal basis. Since the same traffic is created within the computer for both sets of network configurations, the resulting simulation outputs are directly comparable. As a consequence, the survivability components and ANA figures of the various networks, as presented in the TOPS/NETS output summary sheets "Network Data and Simulation Run Characteristics", allow easy determination whether, in which way, and by how much the 'Improved' network is better than the 'Proposed' configuration from a communication survivability point of view.

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* For a detailed discussion see Section 2.3 "Computation of Inferred Traffic Demands."

Both the 'Proposed' and the 'Improved' network configurations have been investigated with link outage probabilities of 10%, 20%, and 50% respectively. The data sheets of Section 4 represent the input information (describing the various network configurations), and the NETS/TOPS output summaries (obtained as the result of Monte Carlo simulations of these networks under attack).

3.1 Simulation Results of 'Proposed' Network Configurations

Simulation runs have been conducted for the following networks:

- Proposed Microwave LOS network for Germany (5.)
- Proposed Millimeter wave LOS network for Germany (6.)
- Proposed Microwave and millimeter Mix-I for Germany (7.)
- Proposed Microwave and millimeter MIX-II for Germany (8.)
- Proposed Microwave LOS network for Oahu, Hawaii (12.)
- Proposed Fiber optics network for Oahu, Hawaii (14.)

The ANA figures and their sub-components for the proposed network for Germany (5) through (8) and Hawaii (12) and (14) are readily compared:

Networks With 10% Probability Of Link Outages:

	(5)	(6)	(7)	(8)	(12)	(14)	Average
PSV_{10}	.972	.918	.952	.930	.927	.912	.935
PTA_{10}	.996	.995	.996	.995	.997	.997	.996
CSV_{10}	.905	.895	.766	.877	.907	.927	.879
ANA_{10}	.876	.817	.726	.812	.839	.842	.819

Networks With 20% Probability Of Link Outages:

	(5)	(6)	(7)	(8)	(12)	(14)	Average
PSV_{20}	.878	.691	.793	.826	.838	.859	.814
PTA_{20}	.996	.995	.996	.995	.997	.997	.996
CSV_{20}	.857	.877	.758	.823	.851	.855	.837
ANA_{20}	.749	.603	.599	.677	.711	.732	.678

Networks With 50% Probability Of Link Outages:

	(5)	(6)	(7)	(8)	(12)	(14)	Average
PSV_{50}	.343	.201	.280	.246	.459	.347	.313
PTA_{50}	.996	.997	.997	.997	.998	.997	.997
CSV_{50}	.850	.886	.809	.881	.795	.867	.848
ANA_{50}	.290	.178	.226	.216	.364	.300	.264

The networks, in spite of their different configurations and link capacity allocations, show remarkable similarities with regard to their survival behavior under various attack scenarios. It is possible, therefore, to make some general comments on an 'average' network basis.

For example, the decrease in the ANA figures is somewhat greater than the probability of link outages (an average of ANA_{10} = .82 for the 10% link outage probability, and an average of ANA_{20} = .68 for a destruction scenario of 20%). Beyond this point the survivability for the networks in question deteriorates even more rapidly. For a 50% probability of link outage the average survivability is way down to an ANA_{50} of .26. This means that almost three quarters of all node pairs (74%) can no longer communicate with each other sufficiently. While there are some variations from those

'average' figures, the general trend is clear. The 'Proposed' networks by themselves provide only a fair resistance against light attacks. They will deteriorate seriously at higher link outage levels.

3.2 Simulation Results of 'Improved' Network Configurations

Configurations have been specified for the following networks:

- Improved Microwave LOS network for Germany (5.)
- Improved Millimeter wave LOS network for Germany (6.)
- Improved Microwave and millimeter Mix-I for Germany (7.)
- Further Improved Microwave and millimeter Mix-I for Germany (*7.)
- Improved Microwave LOS network for Oahu, Hawaii (12.)
- Improved Fiber optics network for Oahu, Hawaii (14.)

For these runs the specified changes in network configuration and link capacities have been implemented. Individual link capacities have been increased also to some extent by the fact that the designated 'spare' channels were added to the 'regular' traffic channels. (This had not been done originally for the 'Proposed' network configurations of Section 4.2).

The simulation results, consequently, show some improvement in survivability, particularly in the area of lesser link outage probability. However, the very strong decline in ANA values for the 50% link outage cases indicate, that a significantly higher degree of threat-resistance has not been achieved.

A closer inspection of the three survivability components PSV, PTA, and CSV reveals, that the path survivability PSV is clearly the culprit responsible for the relatively bad performance. Thus it seems that the situation can barely be improved through further capacity enhancement of existing links. Rather, improvements in network configurations (additional links) are called for, or the operational integration with other existing networks to be used for rerouting in an emergency.

3.2.1 Path Survivability Considerations

In this context it is worthwhile to note that the calculated PSV figures are the most reliable components of the ANA equation. This is so because all necessary information to describe the topology of a network was available and has been entered explicitly as links for node-to-node connections into the simulation model. Still, a case can be made that the calculated PSV figures, in practice, must be used with some reservation. The reason for this point of view is simple: Only if the implemented nodes can act as smartly as the optimum routing algorithm (employed in the computer simulations), will the theory and practice be the same. If the actual system can not adapt to random destruction as well, and can not always find an existing path (as the simulation model does), then additional node pairs will not be able to communicate, although a path still exists.

'Dumb' nodes with fixed routing doctrines and some preprogrammed alternate routes -- which represent only a miniscule part of all potential routing possibilities -- must therefore be considered the greatest obstacles towards achieving survivable communications. Fortunately, built-in intelligence comes relatively cheap nowadays, and can be expected to become even less expensive in the future. Compared with the potentially much higher costs of improving network topologies themselves through the addition of more and more links, the use of computerized 'smart' nodes is the most important first step in the cost-effective design of survivable systems.

In this context, one must keep in mind that communications hardware and operational procedures go hand in hand to achieve the desired results. The theorectical invulnerability of given networks through alternate routes is of little practical value if surviving paths cannot be determined quickly in an emergency. Thus, improved network configurations alone are not likely to do the job. Processing capabilities for automatic link status reporting and routing adaptation must also be implemented. The latter are essential prerequisites for cost-effective design of threat-resistant communication systems.

3.2.2 Detailed Design Improvements

A case can be made that the calculated PSV figures are on the 'pessimistic' side, implying that in practice the situation will not be quite as bad as indicated by the simulation results. The argument is as follows:

The communication survivability between some pairs of nodes may be less critical than the communication survivability of others. If the important nodes are located in 'denser' portions of the network -- indicated by a higher number of links per node and a greater number of interconnections -- then these nodes will have a better chance of maintaining communications with each other. Less important nodes with fewer interconnections, usually located on the 'periphery' of the network, are more readily isolated by hostile actions.

The simulation model used here assumes equal importance or weights for each node pair in the system. Hence, the overall PSV figure is lowered somewhat by the reduced communication survival probabilities of less important node pairs. As a consequence, the situation for important node pairs could actually turn out to be better than the computed PSV figure would indicate.

To remedy this imbalance, a weighting scheme reflecting the relative importance of communications between specific node pairs would have to be established and considered by the simulation program. Furthermore, the capability of the TOPS/NETS program package to produce detailed statistics for each node pair in the system would have to be invoked. This, of course, would have exceeded the purpose and scope of the current task.

For future efforts, however, it should be kept in mind that the above outlined argument is a valid one. Since it can greatly influence the cost picture of communication network planning, it is of significant practical value. Seemingly imperfect, vulnerable networks can be made quite survivable for those node-to-node communications that are really important in emergency situations. Thus, through a painstaking, detailed design effort the desired degree of threat-resistance for important node-pairs can be reached at a much smaller cost. In contrast, similar results obtained through overall improvements of the network would required substantially higher expenditures.

4. Network Simulation Data

The following sections contain the network specifications and simulation results for the following network configurations:

'Minimum' (4.1)

'Proposed' (4.2)

'Improved' (4.3)

NOTE BY TRW

The next three pages are sample input data and print out sheet of NETS program. The input data has been omitted because of difficulty to follow without explanation. The following tables are the tabulated output data of NETS program. Note that no data for improved microwave and millimeter wave mix II for Germany. Besides that data of minimum network has also been omitted.

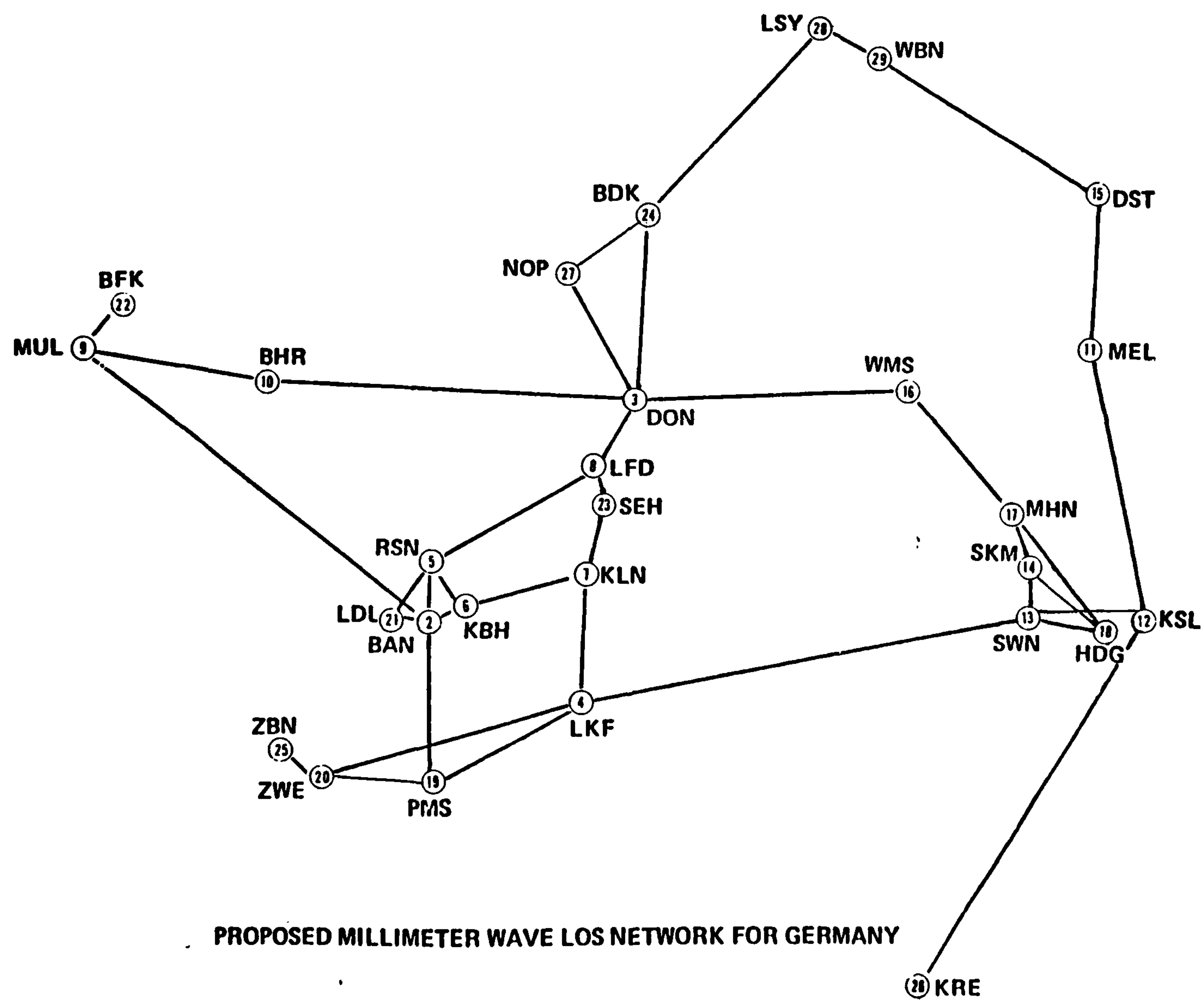
NETWORK CONFIGURATION TO BE ANALYZED

(BASED ON INFERRED TRAFFIC DEMAND PROVIDED BY THE MINIMUM NETWORK CONFIGURATION)

RL / CAPACITY TRANSLATIONS:

RL-FIGURE		CAPACITY	LAST
1.	-	34.50	0
2.	-	26.00	0
3.	-	22.50	0
4.	-	21.00	0
5.	-	19.50	0
6.	-	15.00	0
7.	-	14.00	0
8.	-	13.00	0
9.	-	11.00	0
10.	-	10.00	0
11.	-	9.00	0
12.	-	7.50	0
13.	-	5.00	0
14.	-	4.00	0
15.	-	3.00	0
16.	-	1.50	1

FROM	TO	RL	TABL	LAST	LINK SPECIFICATIONS		
2	6	13.	0.	0	BAN	-	KBH
2	21	13.	0.	0	BAN	-	LDL
2	9	4.	0.	0	BAN	-	MUL
2	19	8.	0.	0	BAN	-	PHS
2	5	8.	0.	0	BAN	-	RSN
3	24	13.	0.	0	BDK	-	DON
24	28	15.	0.	0	BDK	-	LSY
9	22	13.	0.	0	BFK	-	MUL
3	10	11.	0.	0	BHR	-	DON
9	10	12.	0.	0	BHR	-	MUL
3	8	1.	0.	0	DON	-	LFD
3	27	16.	0.	0	DON	-	NOP
3	16	7.	0.	0	DON	-	WMS
11	15	14.	0.	0	DST	-	MEL
15	29	16.	0.	0	DST	-	WBN
14	18	4.	0.	0	HOG	-	SKM
13	18	8.	0.	0	HOG	-	SWN
6	7	3.	0.	0	KBH	-	KLN
5	6	13.	0.	0	KBH	-	RSN
4	7	11.	0.	0	KLN	-	LKF
7	23	4.	0.	0	KLN	-	SEH
12	26	15.	0.	0	KRE	-	KSL
11	12	13.	0.	0	KSL	-	MEL
12	13	9.	0.	0	KSL	-	SWN
5	21	5.	0.	0	LDL	-	RSN
5	8	2.	0.	0	LFD	-	RSN
8	23	3.	0.	0	LFD	-	SEH
4	19	9.	0.	0	LKF	-	PHS
4	13	10.	0.	0	LKF	-	SWN
4	20	13.	0.	0	LKF	-	ZWE
14	17	4.	0.	0	MHN	-	SKM
16	17	7.	0.	0	MHN	-	WMS
13	14	6.	0.	0	SKM	-	SWN
24	27	15.	0.	0	BDK	-	NOP
17	18	16.	0.	0	HOG	-	MHN
28	29	15.	0.	0	LSY	-	WBN
19	20	13.	0.	0	PHS	-	ZWE
20	25	14.	0.	1	ZBN	-	ZWE



PROPOSED MILLIMETER WAVE LOS NETWORK FOR GERMANY

TOPS/NETS

NETWORK DATA AND SIMULATION RUN CHARACTERISTICS

NUMBER OF DCS NODES IN NETWORK:	28 NODES
NUMBER OF DCS NODE PAIRS (LENGTH OF ROUTING DIRECTORY):	378 PATHS
ASSUMED CHANCE FOR LINK OUTAGES DUE TO HOSTILE EVENTS:	$\boxed{10.0 \text{ PCT}}$
ASSUMED LINK TIME AVAILABILITY LTA (OUTAGES DUE TO TECHN.FACTORS):	0.999
DAMAGED NETWORKS (NUMBER OF RANDOM CASES INVESTIGATED):	10 CASES

SURVIVAL PROBABILITIES AND AVERAGE NETWORK AVAILABILITY (ANA)

PATH SURVIVABILITY	CONSIDERING OUTAGES OF COMMUNICATION PATHS DUE TO HOSTILE EVENTS	PSV = 0.918
ROUTING COMPLEXITY	AVERAGE NO OF LINKS PER PATH DUE TO ROUTING/REROUTING OF SURVIVING TRAFFIC	ALC = 4.867
PATH TIME AVAILABILITY	CONSIDERING ROUTING PATH COMPLEXITIES AND TECHNICAL LINK OUTAGES	PTA = 0.995
CAPACITY SURVIVABILITY	CONSIDERING USEFUL CAPACITIES OF BEST SURVIVING PATHS	CSV = 0.895
AVERAGE NETWORK AVAILABILITY	COMPOSITE FIGURE THAT COMBINES THE PROBABILITIES (PSV*PTA*CSV)	ANA = 0.817

THE EFFECTS OF ACROSS-THE-BOARD LINK CAPACITY ENHANCEMENTS

LINK CAPACITY MODIFICATION FACTORS:		1.00	1.10	1.20	1.30	1.40	1.50
CAPACITY SURVIVABILITY:	CSV =	0.895	0.906	0.912	0.917	0.922	0.927
AVER. NETWORK AVAILABILITY:	ANA =	.817	0.827	0.833	0.838	0.842	0.846

NFTS Results of Proposed LOS Network for Hawaii

Number of Nodes		13		
Number of Node Pairs		78		
Link Time Availability		0.999		
Number of Random Cases		10		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.927	0.838	0.459
Routing Complexity (ALC)		2.671	2.723	2.461
Path Time Availability (PTA)		0.997	0.997	0.998
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.907	0.851	0.795
	Average Network Availability (ANA)	0.839	0.711	0.364
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.916	0.863	0.811
	Average Network Availability (ANA)	0.847	0.721	0.371
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.924	0.874	0.826
	Average Network Availability (ANA)	0.855	0.731	0.378
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.932	0.885	0.840
	Average Network Availability (ANA)	0.861	0.740	0.384
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.938	0.894	0.852
	Average Network Availability (ANA)	0.867	0.748	0.390
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.943	0.902	0.864
	Average Network Availability (ANA)	0.872	0.754	0.395

NETS Results of Proposed Fiber Optic Network for Hawaii

Number of Nodes		13		
Number of Node Pairs		78		
Link Time Availability		0.999		
Number of Random Cases		10		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.879	0.750	0.312
Routing Complexity (ALC)		2.781	2.622	2.321
Path Time Availability (PTA)		0.997	0.977	0.998
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.908	0.893	0.865
	Average Network Availability (ANA)	0.796	0.668	0.269
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.916	0.902	0.876
	Average Network Availability (ANA)	0.807	0.675	0.272
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.923	0.910	0.886
	Average Network Availability (ANA)	0.809	0.681	0.275
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.929	0.917	0.895
	Average Network Availability (ANA)	0.815	0.686	0.278
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.935	0.922	0.903
	Average Network Availability (ANA)	0.820	0.690	0.281
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.940	0.928	0.910
	Average Network Availability (ANA)	0.824	0.694	0.283

NETS Results of Proposed Microwave LOS Network for Germany

Number of Nodes		28		
Number of Node Pairs		378		
Link Time Availability		0.999		
Number of Random Cases		10		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.972	0.878	0.343
Routing Complexity (ALC)		3.710	3.870	3.624
Path Time Availability (PTA)		0.996	0.996	0.996
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.905	0.857	0.850
	Average Network Availability (ANA)	0.876	0.749	0.290
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.933	0.891	0.864
	Average Network Availability (ANA)	0.903	0.779	0.295
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.939	0.901	0.876
	Average Network Availability (ANA)	0.909	0.787	0.299
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.944	0.909	0.888
	Average Network Availability (ANA)	0.915	0.795	0.303
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.949	0.917	0.895
	Average Network Availability (ANA)	0.918	0.801	0.306
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.952	0.923	0.903
	Average Network Availability (ANA)	0.922	0.807	0.308

NETS Results of Proposed Millimeter Wave LOS Network for Germany

Number of Nodes		28		
Number of Node Pairs		378		
Link Time Availability		0.999		
Number of Random Cases		10		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.918	0.691	0.201
Routing Complexity (ALC)		4.876	4.549	3.221
Path Time Availability (PTA)		0.995	0.995	0.997
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.895	0.877	0.886
	Average Network Availability (ANA)	0.817	0.603	0.178
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.906	0.886	0.894
	Average Network Availability (ANA)	0.827	0.609	0.179
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.912	0.893	0.902
	Average Network Availability (ANA)	0.833	0.614	0.181
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.917	0.900	0.909
	Average Network Availability (ANA)	0.838	0.619	0.182
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.922	0.906	0.915
	Average Network Availability (ANA)	0.842	0.623	0.183
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.927	0.911	0.921
	Average Network Availability (ANA)	0.846	0.626	0.185

NETS Results of Proposed Microwave and Millimeter Wave Mix I for Germany

Number of Nodes		28		
Number of Node Pairs		378		
Link Time Availability		0.999		
Number of Random Cases		10		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.952	0.793	0.280
Routing Complexity (ALC)		3.884	3.812	3.363
Path Time Availability (PTA)		0.996	0.996	0.997
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.766	0.758	0.809
	Average Network Availability (ANA)	0.726	0.599	0.226
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.813	0.866	0.830
	Average Network Availability (ANA)	0.771	0.632	0.232
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.839	0.825	0.844
	Average Network Availability (ANA)	0.796	0.651	0.236
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.861	0.846	0.855
	Average Network Availability (ANA)	0.816	0.668	0.239
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.881	0.864	0.865
	Average Network Availability (ANA)	0.835	0.682	0.242
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.897	0.879	0.874
	Average Network Availability (ANA)	0.851	0.694	0.244

NETS Results of Proposed Microwave and Millimeter Wave Mix II for Germany

Number of Nodes		28		
Number of Node Pairs		378		
Link Time Availability		0.999		
Number of Random Cases		10		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.945	0.829	0.237
Routing Complexity (ALC)		4.567	4.580	3.114
Path Time Availability (PTA)		0.995	0.995	0.997
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.874	0.815	0.908
	Average Network Availability (ANA)	0.823	0.672	0.214
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.885	0.823	0.918
	Average Network Availability (ANA)	0.832	0.683	0.217
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.894	0.840	0.926
	Average Network Availability (ANA)	0.841	0.693	0.219
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.902	0.851	0.934
	Average Network Availability (ANA)	0.349	0.702	0.220
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.909	0.860	0.940
	Average Network Availability (ANA)	0.855	0.709	0.222
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.914	0.868	0.945
	Average Network Availability (ANA)	0.860	0.716	0.223

NETS Results of Proposed Microwave and Millimeter Wave Mix II for Germany

Number of Nodes		28		
Number of Node Pairs		378		
Link Time Availability		0.999		
Number of Random Cases		100		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.936	0.826	0.246
Routing Complexity (ALC)		4.567	4.663	3.434
Path Time Availability (PTA)		0.995	0.995	0.997
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.877	0.823	0.881
	Average Network Availability (ANA)	0.812	0.677	0.216
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.889	0.837	0.890
	Average Network Availability (ANA)	0.823	0.689	0.218
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.899	0.849	0.898
	Average Network Availability (ANA)	0.832	0.698	0.220
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.907	0.859	0.905
	Average Network Availability (ANA)	0.840	0.707	0.222
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.914	0.868	0.911
	Average Network Availability (ANA)	0.846	0.714	0.223
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.920	0.875	0.917
	Average Network Availability (ANA)	0.851	0.720	0.225

NETS Results of Improved LOS Network for Hawaii

Number of Nodes		12		
Number of Node Pairs		66		
Link Time Availability		0.999		
Number of Random Cases		25		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.987	0.970	0.618
Routing Complexity (ALC)		2.419	2.599	2.743
Path Time Availability (PTA)		0.998	0.997	0.997
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.968	0.802	0.733
	Average Network Availability (ANA)	0.953	0.775	0.452
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.972	0.821	0.754
	Average Network Availability (ANA)	0.957	0.794	0.465
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.975	0.836	0.772
	Average Network Availability (ANA)	0.951	0.809	0.476
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.979	0.850	0.788
	Average Network Availability (ANA)	0.964	0.822	0.486
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.981	0.864	0.803
	Average Network Availability (ANA)	0.967	0.835	0.495
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.983	0.875	0.816
	Average Network Availability (ANA)	0.969	0.847	0.503

NETS Results of Improved Fiber Optic Network for Hawaii

Number of Nodes		13		
Number of Node Pairs		78		
Link Time Availability		0.999		
Number of Random Cases		25		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.964	0.953	0.470
Routing Complexity (ALC)		2.699	2.950	2.911
Path Time Availability (PTA)		0.997	0.997	0.997
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.979	0.939	0.848
	Average Network Availability (ANA)	0.942	0.892	0.398
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.984	0.950	0.860
	Average Network Availability (ANA)	0.946	0.902	0.403
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.936	0.958	0.871
	Average Network Availability (ANA)	0.948	0.910	0.409
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.988	0.963	0.881
	Average Network Availability (ANA)	0.950	0.915	0.413
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.990	0.968	0.890
	Average Network Availability (ANA)	0.952	0.919	0.417
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.991	0.972	0.898
	Average Network Availability (ANA)	0.953	0.923	0.421

NETS Results of Improved Microwave LOS Network for Germany

Number of Nodes		28		
Number of Node Pairs		378		
Link Time Availability		0.999		
Number of Random Cases		25		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.957	0.910	0.368
Routing Complexity (ALC)		3.680	4.114	3.787
Path Time Availability (PTA)		0.996	0.996	0.996
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.946	0.899	0.892
	Average Network Availability (ANA)	0.902	0.814	0.328
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.953	0.911	0.904
	Average Network Availability (ANA)	0.909	0.825	0.332
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.959	0.920	0.914
	Average Network Availability (ANA)	0.915	0.834	0.336
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.965	0.929	0.923
	Average Network Availability (ANA)	0.920	0.842	0.339
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.969	0.936	0.930
	Average Network Availability (ANA)	0.924	0.848	0.341
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.972	0.942	0.936
	Average Network Availability (ANA)	0.927	0.854	0.344

NETS Results of Improved Millimeter Wave LOS Network for Germany

Number of Nodes		28		
Number of Node Pairs		378		
Link Time Availability		0.999		
Number of Random Cases		25		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.946	0.882	0.278
Routing Complexity (ALC)		4.401	4.530	3.374
Path Time Availability (PTA)		0.996	0.995	0.997
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.854	0.817	0.871
	Average Network Availability (ANA)	0.805	0.717	0.241
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.872	0.835	0.885
	Average Network Availability (ANA)	0.820	0.733	0.245
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.883	0.850	0.896
	Average Network Availability (ANA)	0.832	0.746	0.248
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.894	0.863	0.906
	Average Network Availability (ANA)	0.842	0.758	0.251
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.903	0.875	0.913
	Average Network Availability (ANA)	0.851	0.768	0.253
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.911	0.885	0.920
	Average Network Availability (ANA)	0.858	0.776	0.255

NETS Results of Improved Microwave and Millimeter Wave Mix I for Germany

Number of Nodes		28		
Number of Node Pairs		378		
Link Time Availability		0.999		
Number of Random Cases		25		
Link Outage Percentage		10	20	50
Path Survivability (PSV)		0.967	0.886	0.365
Routing Complexity (ALC)		3.551	3.742	3.592
Path Time Availability (PTA)		0.996	0.996	0.996
Link Capacity Modification Factor 1.0	Capacity Survivability (CSV)	0.730	0.692	0.701
	Average Network Availability (ANA)	0.703	0.611	0.255
Link Capacity Modification Factor 1.1	Capacity Survivability (CSV)	0.750	0.714	0.722
	Average Network Availability (ANA)	0.723	0.630	0.263
Link Capacity Modification Factor 1.2	Capacity Survivability (CSV)	0.768	0.732	0.739
	Average Network Availability (ANA)	0.740	0.647	0.259
Link Capacity Modification Factor 1.3	Capacity Survivability (CSV)	0.785	0.749	0.754
	Average Network Availability (ANA)	0.756	0.662	0.274
Link Capacity Modification Factor 1.4	Capacity Survivability (CSV)	0.801	0.765	0.767
	Average Network Availability (ANA)	0.772	0.676	0.279
Link Capacity Modification Factor 1.5	Capacity Survivability (CSV)	0.817	0.780	0.778
	Average Network Availability (ANA)	0.787	0.689	0.283

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